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Factors that influence visual attention and their effects on safety in driving: an eye movement tracking approach

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FACTORS THAT INFLUENCE VISUAL ATTENTION AND THEIR EFFECTS ON SAFETY IN DRIVING: AN EYE MOVEMENT TRACKING APPROACH

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Statistics show that a high percentage of road related accidents are due to factors that cause impaired driving. Since information extraction in driving is predominantly a visual task, visual distraction and its implications are therefore important safety issues. The main objective of this research is to study some of the implications of demands to human's attention and perception and how it affects performance of tasks such as driving. Specifically, the study aims to determine the changes that occur in the visual behavior of drivers with different levels of driving experience by tracking the movement of the eye; examine the effects of different levels of task complexity on visual fixation strategies and visual stimulus recognition; investigate the effects of secondary task on attentional and visual focus and its impact on driving performance; and evaluate the implications of the use of information technology device (cellular phone) while driving on road safety.

Thirty-eight students participated in the study consisting of two experiments. In the first experiment, the participants performed two driving sessions while wearing a head mounted eye tracking device. The second experiment involved driving while engaging in a cellular phone conversation. Fixation location, frequency, duration and saccadic path, were used to analyze eye movements. The study shows that differences in visual behavior of drivers exist; wherein drivers with infrequent driving per week fixated more on the dashboard area than on the front view ($F_{(3,26)} = 3.53$, $p<0.05$), in contrast to the driver with more frequent use of vehicle per week where higher fixations were recorded in the front/center view ($F_{(3,26)} = 4.26$). The degree of visual distraction contributes to the deterioration of driving resulting to 55% more driving errors

committed. Higher time where no fixation was detected was observed when driving with distraction (from 96% to 91% for drivers with less frequency of vehicle use and 55% to 44% for drivers with more frequent use of vehicle). The number of pre-identified errors committed increased from 64 to 81, due to the effect of visual tunneling. This research presents objective data that strengthens the argument on the detrimental effects of distraction in driving.

CHAPTER 1

INTRODUCTION

The present trend in the era of human development is directed towards overcoming the division that separates one society from another. Our ability to use technology for transportation and communication for this purpose has led to changes in how we function in our everyday lives. The use of transportation vehicles as a necessity rather than as a luxury has long been acknowledged. Humans have been using vehicular transport in varying forms and fashion without fully comprehending the complexity associated with operating a vehicle and the effects it might have on their safety. Complicating it even more is the combination of the primary task (i.e., driving) with other secondary tasks (e.g. operating radio, AC, talking with passengers, using a cellphone, reaching for objects, etc.), whether they are characterized as mental or physical activities. It seems that for reasons clear to many, humans have the inherent willingness to engage in associated risk of distracting activities when driving their vehicle.

The rate of accidents associated with the use of vehicles has always been very alarming. The costs to both human lives and properties due to accidents that involves vehicles are overwhelming. A quick look at statistics from a report of the National Highway Safety and Traffic Administration (NHSTA) reveals a disturbing trend. Based on the agency's Fatality Analysis Report (NHSTA FAR, 2004), there were an estimated 6 million motor vehicle traffic crashes in the United States alone at costs that exceed 230 billion dollars. There were no significant improvements from previous reports which showed that one accident occurs every five seconds on US highways. In 2004, police reported over 6.2 million vehicle crashes. Almost one-third of these crashes resulted in an injury, with less than one percent of total crashes (38,253) resulting in a death. These statistics have prompted the NHSTA, the government agency mandated to carry out safety programs under the National Traffic and Motor Vehicle Safety Act of 1966 and the Highway Safety Act of 1966, to pass traffic safety laws and encourage private agencies to support traffic safety-related research in crash avoidance, crashworthiness, biomechanics and trauma.

Because vision is an essential aspect of driving, it is not surprising to note that a high percentage of vehicular accidents are attributed to failure in attention and information processing rather than the lack of skills in performing responses to this information (Shinar, 1978 as cited in Recarte, 2000). In many cases, inattention is indicated by the disruption of visual focus as the driving task is performed. As we use our cars and perform the driving tasks, our primary objective is to operate the vehicle according to how each of them is designed. In time, we acquire the necessary skills and habits that characterize our individual driving behavior. At this stage we confidently perform secondary tasks in addition to the primary task. These secondary tasks may include but not limited to, gathering and interpreting information on road and traffic conditions, operating car related controls and displays such as turn signal lights, temperature control, mirror and seat adjustments or endlessly searching for the right radio station or the CD tray. Compounding the multifaceted tasks is the prevalence of in vehicle information technologies (IVTs) used in driving of which the most common are cellular phones, personal digital assistants (PDAs) and electronic navigational aids (e.g. Global Positioning System).

Despite the prevalence of these technologies, legislative measures have been slow to respond to such development. The indecisiveness to act may be a result of lack of convincing statistics about the relationship of road accidents and use of in vehicle technologies. Based on tacit assumptions, many states have started to move in reaction to the issue. The State of New York was the first to regulate the use of cellphone in 2001, while Washington D.C. followed suit in 2004. Like a snowball effect, several states successively followed with Colorado, Delaware, Maryland and Tennessee banning cellphone use while driving in 2005. Still, the existence of regulation does not necessarily equate to implementation.

There are opposing positions on the issues. Some groups have called for regulation which resulted in partial to outright ban on the use of in-vehicle technologies. Many regulations were specific to cellular phone regardless of whether they are handheld or hands free. These groups are composed mainly of transportation research organizations such as the Virginia Tech and Transportation Institute (VTTI). On the other side, organizations such as the American Automobile Association (AAA) as well as some cellular phone companies do not entirely agree on banning their use. The argument is that using a cellular phone is no different than talking with a passenger or listening to the radio. The debate continues as more scientific proof is warranted in order to aid a comprehensive legislation response.

1.1. Rationale

While technological advances in transportation have made great strides in developing vehicles that try to keep up with what modern society desires, these do not come without unfavorable consequences. The ability of humans to perform multiple tasks simultaneously does not necessarily equate to efficiency. In driving, a few seconds and sometimes even just a fraction of a second of visual inattention can lead to driving mistakes which may result in accidents that are often life threatening. The multitasking scenarios are characteristics of many drivers' behavior when operating their vehicle. However, such scenarios possessed inherent dangers to both lives and properties. What are the consequences of these mental activities on driving? Is visual attention a learned skill and thus dependent on the experience level of the drivers. Does fixation to an object and its duration indicate recognition and perception? How should drivers allocate their visual attention? Is there an optimum visual duration to process information in order to generate the correct response? These are just some of the primary questions that have been the subject of many studies conducted in the past. From the fields of psychology and related behavioral sciences to human factors, visual behavior as a source for interpretation of many human behavioral responses to his environment has been used.

1.2. Objectives and Scope of the Study

The increasing complexity of road conditions and the prevalence of technologies that are incorporated in the vehicle while driving have a significant impact on the driving performance. These conditions have been thought to weigh heavily on the limited functional capability of humans. Specifically, in a task such as driving, the affected functional ability is the visual faculty which is the main source of object recognition and information processing. This research studies the visual behavior in a simulated driving task using the central focus of visual fixation as an input measurement. The eye position is measured in terms of its locations with respect to a given visual stimulus using a head mounted eye tracking device. The main objective of this research is to study some of the implications of demands to human's attention and perception and how they affect performance of a task such as driving. Specifically, the study aims to:

- determine the changes that occur in the visual behavior of drivers with different levels of driving experience by tracking the movement of the eye;
- examine the effects of different levels of task complexity on visual fixation strategies and visual stimulus recognition;
- investigate the effects of secondary task on attentional and visual focus and its impact on driving performance; and
- evaluate the implications of the use of information technology device (cellular phone) while driving on road safety.

This research focuses on the driver's ability to perform the driving task successfully given varying conditions of driving and with the addition of secondary tasks. It intends to evaluate the changes in visual behavior of drivers of varying experience level. The visual behavior was measured in terms of eye fixation, frequency and duration. Driving was done in a simulated condition and secondary task was performed using a handheld cellular phone. The driving tasks consisted of three tasks. The first task was driving under simple driving condition, followed by driving under a complex driving condition. The last task was driving under complex condition with the addition of a secondary task. The secondary task is a simulated conversation with a third person using a cellular phone. Finally, in an effort to determine the safety implications of the driving tasks, subjective evaluations of the experiment as well as safety perception of the participants were collected.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

The technological advancement in eye movement detection and measurement, specifically the availability of affordable, faster, more accurate and convenient to use devices have resulted in an increase in studies related to eye tracking. These studies dealt mostly with detection and prediction of movement of the eye and its corresponding interpretation to human behavior. The applications are vast with fields ranging from human-machine system evaluation, cognitive model validation, neuro-psychological tests, computer graphics design, interface evaluation, virtual reality, human performance and safety awareness.

A survey of literatures was conducted in order to form an intuitive impression of the many uses of the human visual system. This literature review collects significant information starting from the anatomical structure of the human eye to the relationship of visual attention to cognition, from summary of eye tracking research to classification of eye movement. This research deals with eye movement detection and measurement, performance driving and the implications of secondary/distractive tasks to safety. Thus the proceeding section focuses on past studies dealing with driving and visual behavior. Furthermore, the literature available is presented here a comprehensive view of the past and most recent research in eye tracking technology and its application.

2.1. The Human Visual System

The survey of literature begins with a presentation of literatures on the human visual system (HVS). This section provides an overview of the anatomy and structure of the human eye as well as the image capturing and information processing.

2.1.1. Anatomy of the Human Eye

In studying eye movement and its interpretive significance on driver's intention, it is necessary to understand the structure of the human eye and know their functions. A brief discussion of the human eye is below.

Often called the "worlds worst camera" and despite some optical imperfections such as spherical aberrations, chromatic aberrations and curvature of field, the eye is remarkably endowed with various mechanisms which reduce its degrading effects. Figure 2.1 shows a diagram of the human eye with the parts as indicated. A brief description for the most important parts as far as this study is concerned is also provided.

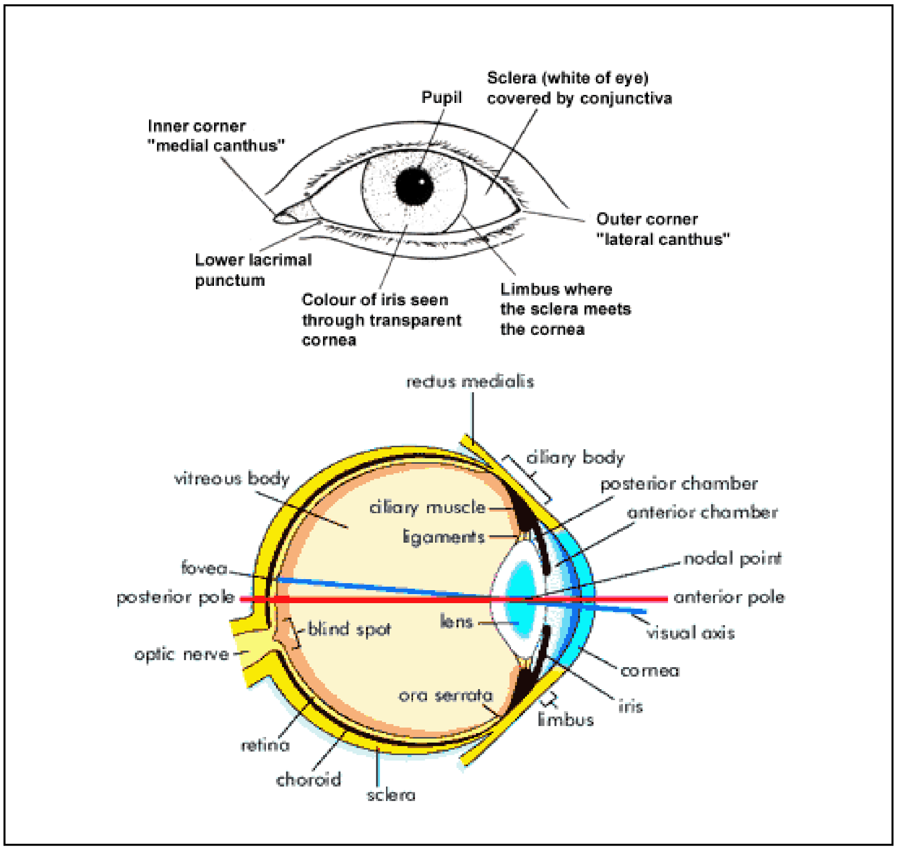

Figure 2.1. Structure of the human eye (*Source:http://www.vision3k.com/)*.

Descriptions of the most important parts are given below.

- The **cornea** is a curved, highly transparent tissue that separates air from clear fluid in the anterior chamber of the eye, which lies between the cornea and lens.
- The **lens** is a firm gel-like transparent tissue that is almost eight millimeters (one-third inch) in diameter and biconvex in shape, that is, thicker in the center than at the edge. A thin transparent capsule surrounds the lens.
- The **iris** is in front of the lens and consists of a circular pigmented muscle that gives the eye its color. The iris acts like the diaphragm of a camera by adjusting the amount of light that enters the eye through the hole in its center which is called the pupil. Light then passes through the vitreous, a clear gel-like material that fills the center of the eye, onto the retina.
- The **retina** is the film of the eye. It is a true extension of the brain and is composed of special nerve cells sensitive to light.
- The **optic nerve** is formed from these nerve cells and carries the light image entering the eye to the brain.

2.1.2. How Vision Occurs

To provide an overview of how the human eye works the following is an excerpt from the website WebMD. “The first thing light touches when entering the eye is a thin veil of tears that coats the front of the eye. Behind this lubricating moisture is the front of the eye, called the cornea. This clear covering helps to focus the light. On the other side of the cornea is more moisture. This clear, watery fluid is the aqueous humor. It circulates throughout the front part of the eye and keeps a constant pressure within the eye. After light passes through the aqueous humor, it passes through the iris. This is the colored part of the eye. Depending on how much light is present, the iris may contract or dilate, limiting or increasing the amount of light that is allowed into the eye. After light flows through the iris it enters the pupil - the black dot in the middle of the eye. The light then goes through the lens. Just like the lens of a camera, the lens of the eye focuses the light. The lens changes shape to focus on light reflecting from near or distant objects. This focused light now beams through the center of the eye. Again the light is bathed in moisture, this time in a clear jelly known as the vitreous. Surrounding the vitreous is the tough, fibrous, white part of the eye known as the sclera which protects the delicate structures inside the eye.

At last, the light reaches its final destination: the retina located at the back of the eye. In a way, the retina is like a movie screen. The focused light is projected onto its flat, smooth surface. Signals sent from the photoreceptors travel along nerve fibers to a nerve bundle at the back of the eye, called the optic nerve. It carries all the information collected from the eye to the brain. Now light has reflected from an object, entered the eye, been focused, and converted into electro-chemical signals. But seeing hasn't yet happened. That's because the eye is only part of the story. Now the brain must receive and interpret the eye's signals. Once this is done, vision occurs" (Haines, 2005).

2.2. Visual Attention and Cognition

Visual attention has long been studied. However, early studies were limited by technology to ocular observations and introspections (e.g. Summala, 1996; Recarte, 2000 Strayer and Drew, 2002; Josephson, 2002). With the advances in technology using eye tracking devices and modern psychological methods that dissects human behavior, the field of visual attention studies includes interdisciplinary collaboration. From the fields of psychology and cognitive neuron-psychology to engineering and computer science, research has been conducted that attempts to explain and predict the human visual predisposition and cognitive abilities.

Visual attention is said to be captured by the features of the stimulus (Crundall, et al., 1999). From the investigation of visual search, the consensus view is that parallel, pre- attentive stage acknowledges the presence of four basic stimuli features. These features are color, size, orientation, presence and direction of motion. The features likely to attract attention include edges and corners but not plain surfaces (Duchowski, 2003). In driving studies, two important subjects that often arise are visual tunneling and peripheral vision. Both have been found to affect driving performance. They are also found to vary based on age and experience as well as complexity of stimuli presentation. The two subjects are discussed in the proceeding section.

2.2.1. Visual Tunneling

Visual tunneling or tunnel vision is the ability to see only straight ahead, after the visual field becomes narrowed and side or peripheral vision is lost (Crundall, et al., 1999). In medical terms, tunnel vision is the loss of peripheral vision with retention of central vision, resulting in a constricted circular tunnel-like field of vision (Frederick, 2003). It is usually caused by alcohol consumption, eye disease (glaucoma), extreme fear, and distress, most often in the context of a panic attack or altitude sickness. In psychology, the failure to recognize when presented a visual stimulus despite the observable focus in eye fixation is attributed to tunnel vision. In vision studies, the occurrences of tunnel vision results form the degradation of the functional field of view. The functional field of view is the area around the fixation point from which information is briefly stored and read out during a visual task (Williams, 1988). It suggests an actual shrinkage of the functional field with the farthest object or most eccentric suffering the most. This narrowing of vision is the closest model to the original idea of reallocating attention from the far peripheral field to the point of fixation (Crundall, et al., 1999).

Tunnel vision is an important topic of research in relation to driving. The accuracy of object detection at different eccentricity required different level of attentional allocation. The addition of other loads as well as multitasking behavior recently have also shown to induce tunnel vision. For example, McCarley, (2004) has shown that attention is degraded even after the conversation between the driver and passenger have finished. The induction of tunnel vision foretells other aspects that may have an effect on driving safety. If tunnel vision was induced, this may reveal further differences between participants with varying driving experience.

2.2.2. Peripheral Vision

The main assumption, in whole or in part, on studies dealing with attention and visual fixation is that attention is gained only when visual fixation is focused on the object. This is not only true in driving studies; but also in evaluation of machine interfaces, studies on the functional field of view (Crundall, et al., 1999) and relevance feedback (Salojarvi, et al., 2003). However, research has shown that this is not always the case. On any tasks, participants do not necessarily focus on the visual stimulus in order to get information. The structure of the human eye allows for perception of stimulus to be visualized without actually focusing the retina, being the first stage of the visual perception, to the object. This means that objects in the periphery have as much of an equal opportunity of perception as objects on the main line of visual field. The ability to perceive objects in the periphery differs for every individual. In driving, the more experienced drivers have different search strategies than their less experienced counterpart. This suggests that drivers may use peripheral vision and that they learn its use over time, depending on the task's demands and eccentricity (Summala, 1996).

Peripheral vision is an important ability that serves important functions when performing different tasks. With few exceptions, road signs are located on the right side of the road and that as they move closer they become more eccentric to the field of view. This increases the frequency of quick transition from one fixation to another as fixation jumps from center to left side. Head position also changes in depending on the proximity of the object. Thus in cases like this, when objects are not seen when they are at the center of the view, peripheral vision is relied upon to perceive the object and process the information that they are conveying. The detection of abrupt changes in the environment depends largely on peripheral vision. Studies conducted demonstrated that the road edges close to the vehicle provide information that is vital to successful lane maintenance. They found that this information was perceived primarily though peripheral vision, as participants rarely fixated these important cues (Land and Horwood, 1995).

In visual attention research, the main issue is whether learned skills or experience allows for wider peripheral visualization ability. Reynolds (1993) as cited in Holmes (1977) found out that five year olds did not seem to employ the fovea first rule in which foveal stimulus is attended to and processed before peripheral processing takes place though eight year olds and adults did. Evidence points to experience as a factor that improves ability to use peripheral visual ability to perceive objects. The participants abilities on a test of the functional field of view show distinct age related visual search deficits (Ball, et al., 1988). These are important studies that may have significant repercussion on road safety. As can be observed, road signs and symbols are supposed to be generic in terms of the driver's ability to see and understand them. However, as shown in many research, novice drivers use different search strategies than the more experienced drivers. One reason as proposed by Chapman and Underwood (1998) is that the less experienced driver has problems with the level of demand placed upon him or her. This entails that the ability to visualize directly or by periphery is affected as cognitive demand increases. Human ability to process information also varies under different conditions and with different stimulus. The information processing models found in literatures that have been proposed attempts to explain the variations. Many are still being challenged. Some of the most significant concepts are presented in the next section.

2.2.3. Human Information Processing and Visual Cognition

The presence of all sorts of stimuli from the environments that may come from one's jobs, homes, while driving one's car and in many other activities that are performed everyday, demands cognitive processing. To make sense of all these information, people use every resource available; eyes, nose, ears, taste buds and sensory receptors of the skin, to decipher the information and give corresponding reactions. The processes by which humans decipher this information consist of several stages in the pathway of information from original source to sensory receptors. The foundations of many of the theories that explain information flow are based and/or adapted from some of the pioneers in psychology of information processing. One of the pioneering model is Broadbent's theory of limited capacity channel (McCormick, 1982), that describes the flow of information within the nervous system as shown on Figure 2.2. The theory presented a model which characterized the nervous system as a single channel with limited rate at which information can be transferred. Filters operate by selecting common features of stimulus protect this limit. These features are then stored in the buffer or are kept in long-term storage. Second generations of information processing models present the short-term memory as replacing the limited capacity communication as the central structure. Haber and Hershenson (1980) proposed the information processing model of hypothetical memory structures. It replaces the limited capacity channel with the short-term memory.

This model is used and adapted in this research to describe the processing of information while receiving a visual stimulus. Generally, the limits of the capacity of human beings for processing information are presumably not universally applicable to all aspects of information processing. Several models have been proposed to explain this information processing using architectures that describe human cognition such as those of Anderson (2004), Newell (1990), and Barnard (1997).

2.2.3.1. Cognitive Architectures: ACT-R, SOAR and ICS

Specialization inexorably continues to move the field of psychology. Integrated theories of the mind have been proposed in an attempt to explain the undergoing processes in the mind. Scientific hypothesis about the aspect of human cognition have been embodied in many cognitive architectures. As cited in Howes (1996), examples range from architectures claiming broad scope, such as SOAR and ACT-R, through ICS or Interacting Cognitive Subsystems to more specialized ones such as Construction-Integration. Adaptive Control of Thought- Rational (ACT-R) is a symbolic cognitive architecture, created by John R. Anderson and others at Carnegie Mellon University in

1998. It has been widely used to model different aspects of human cognitive behavior. It makes use of different forms of symbolic representations such as procedural, declarative and iconic memory. Newell (1990) argued for cognitive architectures that would explain how all the components of the mind worked to produce coherent cognition in his architecture called State, Operator and Results (SOAR).

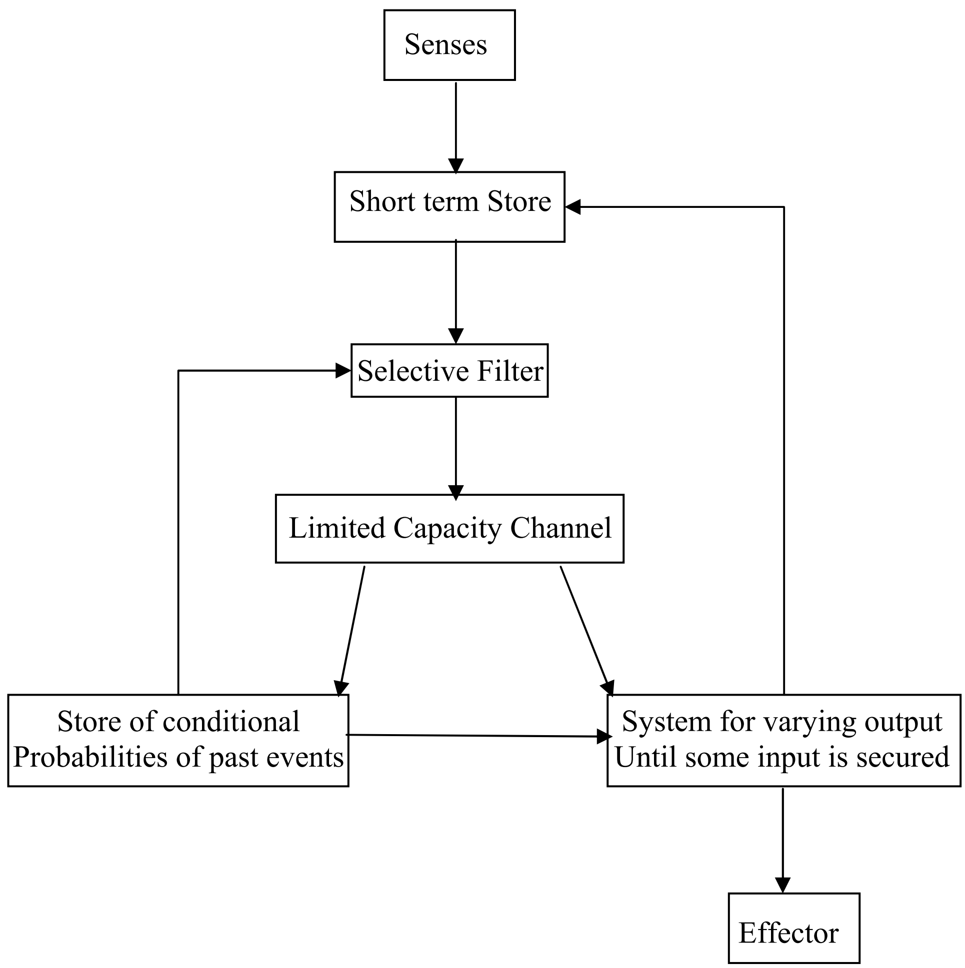

Figure 2.2. Broadbent's model of limited capacity information flow (*Source: McCormick, 1982*).

Like the production system architectures from which it was derived, SOAR has been applied both within artificial intelligence as a vehicle for constructing knowledge-intensive systems, and within psychology for the modeling of human cognition. On the other hand, Barnard (1997) represents the human information processing as a mechanism of highly parallel organization with a modular structure. The ICS architecture contains a set of functionally distinct subsystems, each with equivalent capabilities, yet each specialized to deal with a different class of representation. The assumption is that the architecture is dealing with a system of distributed cognitive resources, in which behavior arises out of the coordinated operation of the constituent parts (Dix, 1997).

The disparity among these models of information processing serve to emphasize the point that there is as yet no widely accepted consensus and many gray areas are still left unexplained about the intricate process leading up to the evident nature of human behavior. With varying degrees of consensus and controversy, there have been claims for separate mechanisms for processing visual objects. Anderson (2004) summarizes visual object recognition with respect to locations for procedural versus declarative knowledge, language, arithmetic, categorical knowledge, and for cheater detection to name a few.

Contributions of cognitive architectures to scientific modeling of the human mind are still in doubt. Despite this consensus, architectures still play their part by imposing theoretical constraints on the models constructed within them. In some cases, such constraints can be strong enough to dictate certain characteristic properties that models exhibit (Howes, 1996). These architectures, argumentatively, lay down the foundation to information processing. Human interaction with computers in today's age leads to some remarkable explanations for the intricacies of processing information using different senses. With respect to visual stimuli, human behavior depends on highly developed abilities to perceive and interpret visual information and provides a medium for the next generation of image retrieval interfaces (Oyekoya, 2004).

Attention is a salient feature of human mentality. Much of the information acquired is through visual faculty. Studies have provided different mechanisms by which humans process information through visual manifestations. For example, studies such as shifts in visual attention independent of eye fixation or changes in spatial location, inhibition-of-return mechanisms (Banich, et al., 2000), and attention in saccades (Fischer, 1998) are just a few of central topic in psychology that builds up the chronology of modern scientific inquiry into the relationships of visual attention and information processing.

2.2.3.2. Visual Presentation and Information Processing

Human information processing starts when visual attention is directed towards particular objects in any given space using our eyes as sensory receptors. The result is faster reflection times to detect or discriminate targets at that location than in location that are not prompted (Mansfield, 2003). Every visual stimulus or arrangement of individual items gives the viewer some information that helps to identify it. To recognize a stimulus is to distinguish that stimulus from anything else that could appear. However, attentional capture varies and information processing is influenced by how we perceive objects in space.

To explain how humans organize objects into meaningful information is difficult. There have been several principles that explain such occurrences: the constructivist and the ecological approaches. Under the constructivist approach, it is believed that individuals have preconceived information from the environment that aids in the organization of objects. One of the goals of information theory is to specify which aspect of the stimulus conveys information about the identity of stimulus (Pylyshyn, 2004). The organizational presentation of stimulus conveys subtle messages that affect how information is perceived. Psychologist at the time were intrigued and attempted to explain the intricacies of the ability of our mind to perceived whole things out of incomplete elements.

In 1890, as a reaction to the prevalent psychological theory of the time which is atomism, the Gestalt theory arose. Atomism examined parts of things with the idea that these parts could then be reconstructed to make wholes (Moore, 1993). The Gestalt theory on the other hand argues that our ability to interpret the meaning of objects and scenes are based on us having innate laws of organization (Preece, 1994). These perceptual organizations include principles of proximity, similarity, closure, continuity and symmetry. The way human process information, according to the Gestalt principle, is that it involves decomposition or partitioning of images into separate entities that are readily recognizable.

Visual objects on a space require presentational characteristics that capture attention. Tversky, et al. (2002) stated that there are wide ranging effects of varying presentation for different objects such as those that portrays things that are essentially visuospatial (e.g. maps, architectural drawings), and those that represent things that are not inherently visual (e.g. organization charts, flow diagrams, and graphs). Objects that are facilitator to the perception and cognition affords better human machine communication. This enables location of target objects in the space more efficient resulting to higher user satisfaction. Literature suggests that students scoring high in spatial abilities should be able to conceptualize the processes of diffusion in animation more completely or to a greater depth of elaboration. Animation provides potential visual interest for presenting computer based materials, which makes scientific learning more appealing and enjoyable to learners (Chan Lin, 2002).

Given the subjective nature of information provided by the cognitive models used in visual research, scientists from many disciplines have attempted to supplement this information with objective measures. The most direct source of objective measure in visual search from the human cognitive point of view is the human visual system. As the human eye is the window that can open up the inner mechanism of human behavioral predisposition, research activities started to focus on developing techniques that would allow for accurate measurement of the eye movement

2.3. Eye Tracking Research

A wide variety of eye tracking research has been conducted in many disciplines. The breadth and scope of these studies range from the human ability to capture the image in a given space, the characteristics of eye movement patterns and its interpretation to intention, the reliability of measuring eye movement and many other topics that is not covered in this research. This study is concerned with the eye gaze patterns and their interpretations as well as the representation of objects and how it affects human performance. These topics are therefore given space in this literature survey.

2.3.1. Characteristics of Eye Gaze Patterns

A number of recent studies have shown that eye gaze and visual attention can automatically trigger the orientation of attention (Drover, 1999; Tipples, 2002;

Mansfield, 2003; Bamidele, 2004). Whether or not eye gaze perception indicates intention is a challenge to many researchers. In order to answer the question “when does the eye move at a given fixation during a search?” and “what makes it move just at this moment?” one must analyze the decision mechanism that is supposed to trigger a saccade and eventually fixation. Jacobs (1987) hypothesized that the cognitive event triggering a saccade in a search situation consists of the achievement of a decision about presence or absence of the sought-for target within the fixated area of the line. Furthermore, at each fixation during search, he stated that the more similarities between the background and the sought for target exist, the harder will be the decision about the presence or absence of the target within visual span. This means that decision time should increase with increase in target-background similarity and consequently the average latency of the saccade.

Tipples (2002) studied the different effects of using symbolic and direct cue objects and found out that the participants were faster to detect target objects in briefly cued locations than in un-cued locations. These findings contradict earlier research that shows that uninformative symbolic cues do not automatically trigger orienting. This study is significant since it shows that perception of eye gaze direction may produce adaptive advantage across human information processing evolution. Henderson and Hollingworth (1998) suggest several metrics for evaluation of relative informative values of scene regions. Generally, first pass gaze durations are longer for semantically informative (i.e., inconsistent) objects. Semantically informative objects also tend to draw longer second pass and total fixation durations. The influence of semantic informative values on the duration of the very first fixation on an object is less clear. That is, scene context has an effect on eye movements: fixation duration on an object that does not belong in the scene is longer than fixation duration on an object that does belong (Rayner, 1998). However, it is not clear whether the longer fixations on objects in violation of the scene reflect longer times to identify those objects or longer times to integrate them into a global representation of the scene. It could also reflect amusement of the absurdity of the violating objection under the given context.

2.3.2. Spatial Working Memory and Graphic Representation of Object

Visual attention requires allocation of limited working memory for the perception of the objects in space. As more objects are presented it affects performance in any visual attention tasks. It has been shown that low working memory participant allocates visual attention based on spotlight whereas those that have high working memory capacity showed flexible allocation (Bleckly, 2003). Consistent with these findings are the results of Lawrence, et al. (2004), which show that any attentional shifts on new objects presented interfered with spatial working memory suggesting that interference is specific to processes within the “visuospatial sketchpad”.

It is important to note on these studies that working memory capacity varies considerably for different individuals. In a study done by Mayer and Moreno (2003), on ways to reduce cognitive load in multimedia learning, they found that working memory affects cognitive load in terms of the three assumptions (dual channel, limited capacity and active processing) on how the mind works in multimedia learning. Visualization of object is crucial for any multimedia application. The graphic representation of objects in any give space has an influence on whether visual cognition will be successful or not. The patterns by which one’s eyes move and perceive the object can be interpreted to indicate an elaboration of the cognitive processes. As such studies using eye movement in many tasks such as driving have been conducted in laboratory setting simulating actual driving conditions.

2.4. Classification of Eye Movement and Eye Tracking Methods

Improvements in eye tracking technology focus on the accuracy and precision of eye movement measurement based on fixations and saccades. Fixation was measured in several studies based on frequency and duration. However, depending on the stimulus presented and how they are presented, eye movements can be broadly split into four types. According to Duchowski (2003), these are:

1. Fixation – These are low velocity eye movements. The exact duration is dependent on task but usually lasts from 200-300 milliseconds. Fixation corresponds to subjects staring at a particular point and contains very small randomly drifting eye movements and quick adjustments to keep the target centered.
2. Saccades - These are rapid eye movements lasting anywhere from 200 to 300 milliseconds, that the eye makes while jumping from point to point in the stimulus. They can be triggered by displaying fixation targets at defined times within the stimulus. Saccades are also studied as movements between points while reading or studying an image.
3. Pursuit – This is eye movement that occurs when the eyes follow a moving target in the environment in order to fix that target on the retina. Normally the eye smoothly tracks a moving object, but in some cases the eye will perform ‘catch-up’ saccades, rapid eye movements intended to reacquire

the target. They are involuntary and are affected by a number of environmental and pathological variables.

4. Gaze Path – This is generally the path the eye takes while studying a stimulus image. Gaze path can be thought of as the chronological ordering of fixations and saccades, or more generally the pattern the eye takes while studying an image.

During saccades visual information is not acquired. The brain processes information only during fixations. Eye movements are based on the velocity, acceleration and previous movement of the eye at a point in time. There are other classifications of eye movements that are of particular importance in the use of eye movement to describe visual behavior. The miscellaneous classification as shown in Table 2.1 are extensions of the main eye movement nomenclature as given above and occurs as a special type of fixation and saccades.

Table 2.1. Eye movement classifications (*Source: Salvucci, 2001*).

Eye Movement	Description
Vergence	Occur during fixation - Inward movement
Vestibular	Occur during fixation - Rotation of eye to compensate for head movement
Nystagmus	Occur during fixation - Tremor in eye due to occulomotor imperfections
Drifts	Occur during fixation - slow movements in eye due to occulomotor imperfections
Micro-saccades	Special type of saccade - short eye movements to correct drifts from fixation points.

2.4.1. Eye Tracking Methods

Eye tracking methods are measured on several different ways. Measurement can be based on changes in polarity of the eye, multiple reflections of light on front and back surfaces of the cornea, through shining infrared light into the eye and illuminating it. In many instances in research methods, head movements are of critical importance in order to achieve accuracy of measurements. Duchowski, (2003) summarized some common eye tracking methods used are:

1. Electro Occulography – Because there are differences between polarity of the eye from back to front, original eye tracking systems tracked electrical field changes as eye moved. These systems are limited in accuracy and extremely susceptible to noise - a record of the standing voltage between the front and back of the eye that is correlated with eyeball movement (as in REM sleep) and obtained by electrodes suitably placed on the skin near the eye.
2. Coil Systems – A coil tracking system tracks eye movements by observing a magnetic coil inserted it the eye surgically or as part of a contact lenses. The head must be fixed by a bite bar or a separate coil must be used for head position analysis. The method is susceptible to noise and the coils can be fragile. This type of eye tracking experiment is invasive and potentially dangerous. Therefore, it is mostly used for animal studies.
3. Dual Purkinje Systems – These systems track multiple reflections of light on the front and back surfaces of the cornea. By geometrically calculating the orientation of these reflections, the eye position can be determined. An algorithm converts this eye position to gaze position. Dual Purkinje systems

are usually very accurate but they require the complete immobilization of the head through the use of an uncomfortable bite bar.

4. Bright Pupil Systems – Shining Infra-Red (IR) light directly into the eye, coaxial with an IR sensitive camera, produces a glowing effect in the cornea. By tracking the movement of this bright reflection, bright pupil systems track orbital eye movements. Using a calibrated algorithm, the system can translate these eye movements to gaze position. Bright pupil systems require some external head tracking method or the head must be immobilized.
5. Dark Pupil systems – The eye is illuminated by IR at an angle from an IR sensitive camera. The eye and face reflects this illumination but the pupil will absorb most IR light and appear as a high contrast dark ellipse. Sophisticated image-analysis software determines where the center of the pupil is located and this is mapped to gaze position via an eye tracking algorithm. Dark pupil systems are versatile and easier to set up, though they also require some kind of head movement compensation. The experiment will use an eye tracking device using the dark pupil system.

2.4.2. Taxonomy of Fixation Identification

The variety of studies using eye tracking system to interpret eye movements and the techniques by which they are measured in many tasks uses algorithms for identification of fixations. Salvucci (2001) stated that most of the identification techniques are statistical description of observed eye movement behavior. Thus, regardless of the precision and flexibility, identification techniques are still a subjective process. He further suggested the following taxonomy useful and meaningful labeling and classification of existing algorithms so that they may be more easily compared in a systematic way to guide the choice of algorithm for particular applications. In the following taxonomy, Salvucci posits that fixation identification is an inherently statistical description of the observed eye movement. He uses representative algorithm such as Velocity Threshold, Hidden Markov Model, Dispersion Threshold, Minimum Spanning Tree, and Areas of Interest.

These algorithms are classified based on spatial and temporal characteristics. The table below shows the criteria for the application of specific algorithm. Velocity Threshold (VT), Minimum Spanning Tree (MST), Hidden Markov Model (HMM), and Dispersion Threshold (DT) are algorithms that can identify fixations at any location in the visual field. On the other hand, Area of Interest (AOI) on the other hand identifies only fixations that occur in specified target areas.

Table 2.2. Taxonomy of fixations (*Source: Salvucci, 2001*).

<table>
<tr><th colspan="2" rowspan="2">Criteria</th><th colspan="5">Representative Algorithm</th></tr>
<tr><th>VT</th><th>HMM</th><th>DT</th><th>MST</th><th>AOI</th></tr>
<tr><td rowspan="3">Spatial</td><td>Velocity based</td><td>X</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>Dispersion based</td><td></td><td></td><td>X</td><td>X</td><td></td></tr>
<tr><td>Area based</td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td rowspan="2">Temporal</td><td>Duration sensitive</td><td></td><td></td><td>X</td><td></td><td>X</td></tr>
<tr><td>Locally adaptive</td><td></td><td>X</td><td>X</td><td>X</td><td></td></tr>
</table>

In a task on a dynamic stimulus, it can provide a larger picture than fixations alone like dwell time, saccades, or gaze paths can provide. As driving is a dynamic task that requires extracting information from dynamic stimulus presentation, the use of these algorithms provide further aid in the evaluation of visual behavior. In this research, AOI were used to evaluate parameters of eye movement in the aim that will help explain higher level collections of fixations about visual targets and areas.

2.5. Studies on the Relationship of Eye Movement and Driving

Generally, humans acquire and process information when performing a driving task using visual sense. The mechanisms in which the eye perceives the object in order to perform appropriate actions have baffled not only psychologists, but also other scientific disciplines as well. It is a common conclusion, especially in the field of psychology and the discipline of human factor, that failure to visually attend to objects on the road that affords appropriate response is one of the major causes of vehicular accidents.

The multiple tasks that drivers need to perform as presented by all driving scenario requires careful assessment of information processing capabilities and the perceptual and attentional demands. The measurement of eye movement through fixations, duration, and saccades has provided researches many insights into the behavioral aspect of information processing in a dynamic scene. Recent advances in technology helped scientist to decode human information processing using visual search and perception which are important characteristics of visual allocation strategy when performing complex tasks such as driving. In the field of Industrial Engineering and Human Factors several studies in driving which incorporated eye tracking are described in Underwood (2004). With respect to this study, eye tracking techniques can be classified in several ways. The classification can be based on eye tracking algorithms, method of measurements, diagnostic, or interactive research. Duchowski (2003) provided an overview of the hierarchy of eye tracking applications as shown in the Figure 2.3. Interactive eye tracking studies are those that include using the device as an input tool which can be utilized by a host of visually-mediated applications. In an interactive system using the eye tracking device, the system is expected to respond or interact with the user. An example of interactive eye tracking systems used as an input device is the Dasher Project (Ward, 2001). This is a word processing application where the user manipulates his/her gaze to type words into the screen. The construction of words uses probabilistic techniques that anticipate the next letters that will likely follow the previous letters. Diagnostic studies in the other hand simply record eye movement to ascertain user's attentional patterns over a given stimulus. More recently used in driving studies, eye movement tracking devices have been used in driving scenarios that deals with topics such as button location and eccentricity (Dukic, 2005), steering (Salvucci, 2004), visual scanning (McCarley, 2004), behavior and cognitive architecture (Salvucci, 2005), and verbal and spatial imagery tasks (Recarte, 2000).

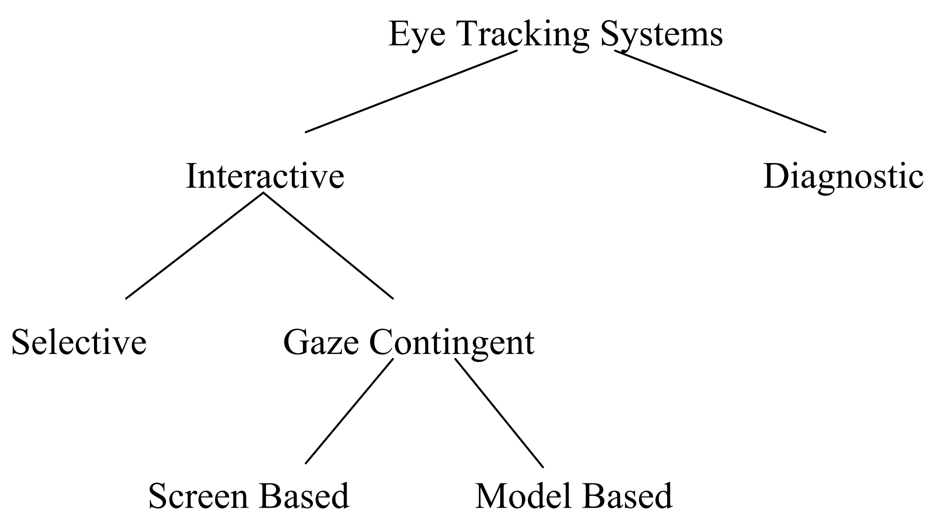

Figure 2.3. Hierarchy of eye tracking applications (*Source: Duchowski, 2003*).

2.5.1. Eye Movement in Dynamic Tasks

As previously stated, driving is a complex task characterized by the dynamic factors that requires the driver to process information continuously and to respond immediately and appropriately. The different stimuli that are presented to the driver must be integrated with respect to the intentions of the tasks. Several researches have focused on the dynamic aspect of the environmental factors and its effect on the performance of the task. Studies in eye movement recording serve to indicate the existence of certain scanning strategies. The analysis of the manner in which a driver's eyes move and fixate may give an indication of the allocation of attention among various information sources. For example, in a video display unit (VDU) and eye movement study by Jacobs (1987), when subjects were trained to work in a self paced condition no strategy changed can be observed, while as time pressure induces change in a person's strategy. Eye movement was found out to be a unique indicator of strategy change in VDU related tasks.

Whether vehicle control is degraded when performing tasks secondary to driving is the subject of several studies performed on driving experimentations on real life road conditions as well as simulated driving scenarios in the confines of the laboratory (see Duchowski, 2003). Text entry tasks while driving experiment conducted by Tarasewich (2003), found out that vehicle control is severely degraded. The severity depends whether the type of text entry method used was touch screen or speech based. Even with excellent accuracy of the text entry, driving performance proceeds not without unfavorable consequences. In dynamic tasks that involve visual function, any addition of secondary tasks contributes to the drop in performance of the primary tasks. This was shown by an experiment with addition of conversational tasks that reduces the functional field of view.

Because similar reductions have been shown to increase crash risk, reductions in the functional field of view by conversation may be an important mechanism involved in increased risk (Atchley and Dressel, 2004). Based on similar experiments, it was found out that in situations of information conflict, participants experience equal task disruption regardless of the sensory channel of the secondary task if the quantity of information presented is carefully controlled (Landsdown, 2002).

2.5.2. Distraction Factors and Visual Behavior

Humans have the inherent willingness to engage in associated risk of distracting activities while operating their vehicle. For many, it seems that the act of driving itself is a skill that has become ingrained in their system that they feel they are confident enough to attend to other tasks no matter how insignificant they are from the primary task of driving. However, such confidence results in many tragic events resulting to loss of lives and properties. The effects of these factors are discussed as follows.

2.5.2.1. The Effect of IVIS in Driving Tasks

A recent article from the Journal of Technology and Society summarizes the prevalence of using in-vehicle information systems (IVIS) while operating a vehicle. The news article describes the magnitude of cell phone prevalence in society. It states "The number of cell phones outnumbered fixed telephone lines. According to industry figures, about 137 million Americans subscribe to cell phone services. Worldwide, there are more than one billion cell phone users and as one wireless industry analyst recently claimed, "sometime between 2010 and 2020, everyone who wants and can afford a cell phone will have one." Americans spend, on average, about seven hours a month talking on their cell phones. Wireless phones have become such an important part of our everyday lives that in July, the country's major wireless industry organization featured the following "quick poll" on its website: "If you were stranded on a desert island and could have one thing with you, what would it be?" The choices: "Matches/Lighter," "Food/Water," "Another Person," "Wireless Phone." (Rosen, 2004, p. 26).

The use and integration of information technology in vehicles have been studied by several researchers because of its significant and often detrimental effect in operating a vehicle. Researchers have made notable strides in the evaluation of commonly used interfaces used as IVIS such as interfaces of cell phones, radio, global position system (GPS) and other similar devices. Performances have been known to affect driver's behavior (Strayer, et al., 2003). Mathews and Sparks (1996) stated that overload of information processing capacity causes problems with driving performance.

Salvucci (2001) predicted that two different manual dialing interfaces would have significant effects on drivers' steering performance while different voice-dialing interfaces would have no significant effect on performance. The effects of using a cell phone when driving have shown that when 19 to 25 year-olds were placed in a driving simulator and talk on a cellular phone, they reacted to brake lights from a car in front of them as slowly as 65 to 74 year-olds who are not using cell phones (Strayer, et al., 2001). Cognitive load problems have been related to the use of mobile phones. Actions such as dialing and driving have impact on driving performance in a variety of ways and with a variety of conversation topic (McKnight and McKnight, 1991). An intense business conversation is shown to differ in social conversations in the cognitive load placed on the driver while operating a vehicle. Experiences seem to play a major role in which we assess and take risks. Based on experience in both the short and long term, human behavior is affected by the process in which objects are instinctively expected in a visual field to behave. This has a profound influence on driver perception and assessment of risk. For all drivers, serious errors of judgment from time to time would seem inevitable. In general, these do not lead to accidents because of, among other things, the safety margins added by the driver and adjustments made by other road users (Hills, 1980).

2.5.2.2. Display Location and Arrangement

In driving and eye tracking studies, different display presentations have been studied as well. In driver's performance, the effect of a heads up display (HUD) and a heads down display (HDD) have shown that in terms of response time to an urgent task, driver's response was faster with HUD and speed control was more consistent (having low speed variations) than with HDD. In addition, it requires less mental stress for the drivers (Liu, 1998). This study also shows that interruptibility of heads down display in terms of visual attention in driving also contributes to a decrease in performance. Over all, the adjacent display set up best supported performance on all relevant tasks (Horrey and Wickens, 2004). A visual attention study using eye tracking machine will more accurately predict the effect of vehicle control display on the driver's visual behavior.

Ironically the purported comfort that IVIS delivers results into a driving task that has become more complicated with the integration of information technology (Ross, 2001; Burnett and Porter, 2001). It offers convenience in terms of living our daily lives in our present society. However the intrusiveness of some of these technologies contributes significantly to vehicular accidents, the causes of which are not entirely different to alcohol related vehicular accidents. In studying visual attention in driving, tasks that are easily interrupted under intermittent viewing conditions may be less distracting while driving because they allow drivers greater control over task sharing decisions (Noy, 2004). Not only does visual distraction contributes to a decrease in performance, but also other forms of alert such as auditory alerts show that reaction time to lead vehicle increases with high urgency alert such as an e-mail alert but not with low urgency alert. Response to lead vehicle improves when e-mail alerts occur during braking events (Wiese and Lee, 2004).

Despite the usefulness of onboard information systems, one has to be concerned about potential distraction effects that they impose on the driver (Dingus, 1989). Results show that occlusion can be used as a procedure for evaluating display designs with regard to visual demand (Burnett, 2001; Baumann, 2004). Objects that deviate from the normal line of sight require compensation to correct any deficiencies. Humans have inherent capacity to compensate eccentricities of objects in the visual field of view. In order to gain insight into possible compensatory mechanisms of these persons, eye movement recordings were used. The results indicate that the visual search pattern may be of importance in this respect. Some comparisons with respect to detection capacity were also made with one-eyed subjects and with optically generated field restrictions - spectacles and spectacle frames (Lovsund, et al., 1991).

Another study by Dukic (2005) shows the expected results that as the visual angle between the normal line of sight and button location increases, the visual time off road to perform secondary task increases. Moreover, the visual time off road tends to be higher for buttons placed in the vertical direction as compared with those placed in the horizontal direction with the same angular deviation from the normal line of sight. The common findings of these studies are the recognition of the need for fundamental research and development to ensure that the control and use of interfaces for future cars require minimal visual demands.

2.5.2.3. Road Traffic Conditions

From anecdotal evidences and preliminary researches in vehicle crashes, it is now evident that distractions can hinder the task of operating a vehicle reducing driver safety eventually leading to some tragic consequences. In general humans assess the safety of the road based on the state of a number of factors. These include, but not limited to road pavement conditions, "smoothness" and curvatures, presence and quantity of road signs, general road regulations an example of which is speed limit, density of traffic as well as the general natural environmental conditions (e.g. weather that might limit visibility in driving). All these factors and many more affect the way one perceived safe driving. In so doing humans allocate visual attention to objects that require immediate attention. However, the dynamic flow of this object at varying vehicle speed intensifies the competition for visual attention thus it complicates the processing of information.

2.6. Workload Management

The multifaceted aspect of driving puts a heavy workload on drivers. Secondary tasks, many of them necessary, are inherent part of the driving behavior while others are now just becoming available as new technology becomes more prevalent. For example, sending emails or text messages in recent studies have shown that drivers compensated for the secondary task by adopting longer headways but show reduced anticipation of braking requirements and shorter time to collision. Drivers were also less reactive when processing E-mails, demonstrated by a reduction in steering wheel inputs. In most circumstances, there were advantages in providing drivers with control over when E-mails were opened. However, during periods without E-mail interaction in demanding traffic scenarios, drivers show reduced braking anticipation. This may be a result of increased cognitive costs associated with the decision making process when using a driver-controlled interface when the task of scheduling E-mail acceptance is added to those of driving and E-mail response. (Jamson, et.al., 2004).

2.6.1. Visual Demand and Allocation of Resources

People often fail to notice large changes to visual scenes in what studies in psychology have termed as change blindness. The extent of change blindness in visual perception suggests limits on our capacity to encode, retain, and compare visual information from one glance to the next. Our awareness of our visual surroundings is far sparser than most people intuitively believe (Simons and Ambinder, 2005). The demand for visual attention from environment for driving is such that allocation of all human resources for perception is necessary in order to effectively perform the primary task. How these demands are assessed depends in an efficient visual distribution of the eye movement. Perception of the environment plays a vital role on how resources are allocated. The perception of visual activity is the main source of information when operating the vehicle. In driving, eye gaze was always highly constrained, regardless of expertise and decreasing speed, and tended to be directed not only toward the drivers' intended path but also anchored on where they intended to stop (Rogers, 2005). Attention therefore is crucial to the visual perception. Any information located in unattended places is scarcely processed or not processed at all (Johnston and Dark, 1986; Theeuwes, 1996 as cited in Recarte, 2000). In planning where the eyes will move in what direction, attention plays an essential role in the strategy to inspect the visual environment

(Anderson, 2004), either towards locations pre-selected by expectations or towards objects that automatically attract attention because of conspicuous or contrasting attributes (Theeuwes, 1996). Machado and Franz (2004) studied the effect of distractors and proposed (1) the appearance of the distractor activates occulomotor cells, which facilitate a subsequent eye movement with the same direction vector, (2) the distinctiveness of the target determines whether color and side congruency interact, and (3) spatial codes mediate the interaction between color and side congruency that occurs when the target is sufficiently distinct from the distractor.

Eye movement is fractioned to allow maintenance of critical items such as road signs, presence and location of other vehicles relative to vehicle in focus, and biased against those that are not immediately relevant to the tasks (Downings and Dodds, 2004). Adequacy of the eye fixations (supposedly influenced by prior long-term learning) is essential where information at near distance for vehicle control and at longer distances for setting propioceptive forward programs for possible future sensomotoric activity (Cohen, 1997). Thus it has been advocated that the gist of the scene is abstracted on the first few fixations, and the remainder of the fixations on the scene are used to fill in details in the same manner that much of the global information about the scene background or setting is extracted during the initial fixation (Rayner, 1998).

2.7. Summary: The Need to Do More Studies

The results of past studies vary as the technology for eye tracking continues to improve in accuracy and precision. The lack of a comprehensive studies dealing with visual behavior and driving forced many researchers to rely simply on passive observations on the causes of accidents related to driver distraction. Different methods such as installing video cameras to monitor the vehicle and the driver and historical analysis of the causal factors of vehicular accidents does not provide enough quantitative information of the effects of several important factors that affect our driving behaviors. Few objective data provides credence on the many implications of distraction resulting to the hesitation of many countries to make legislations on the use of in vehicle technologies. The key to the development of measures that effectively counter the effects of vehicular crashes is to quantitatively evaluate the factors that contribute to such events. In this regard, there is a need to quantify the effects of factors affecting human actions when driving. Research should focus on quantifying the factors associated with human behavior using measurable human reactions. In this regard, the use of the human visual system is a promising behavioral input that could provide interpretations to human actions. The technology that provides a reliable measurement with high accuracy and precision of eye movement is now available thus providing more impetus to conduct research on the use of the central visual focus as input to measuring and interpreting human behavior.

CHAPTER 3

METHODS AND PROCEDURES

This chapter details the description of participants, equipment, general experimental procedures, and methods of data collection and analysis. The experiment was composed of two sessions. Specific procedures are outlined in details under the respective experimental tasks.

3.1. Participants

A total of 50 participants with different levels of driving experience participated in the study (Appendix A). Based on an estimate from the pilot study performed, a sample size between 25 to 50 participants was used. This estimate concurs with previous and similar studies done in eye tracking and driving (Crundall, et al., 1999; Sodhi, et al., 2002; Strayer and Drew, 2003; Hayashi, 2005). All participants were either graduate (10%) or undergraduate (90%) students of Louisiana State University (LSU) and participated in the experiment on a voluntary basis. No monetary compensation was given for participating. The participants were comprised of 35 males and 15 females with an average age of 22.12 years (s.d. 2.62). All participants possessed a valid driver's license and 97% owned a cell phone. Participants who took part in the study indicated they are in good general health prior to the experiment. While some participants wear contact lenses and eyeglasses, none reported any major visual and hearing impairment. They also stated good familiarity with standard American road signs. The participants also indicated that they were adept in driving an automatic transmission type vehicle. Before any data was collected, all participants read and signed an informed consent form (Appendix B) complying with the IRB application and approval (Appendix C).

3.2. Equipment

The equipment used in the study included a driving simulator, an eye tracking system, digital video cameras, computers and cellular phones. The equipment and materials used to conduct the experiment are described in details.

3.2.1. Driving Simulator

The driving simulator used in this experiment was a fixed-based simulator located in the Human Factors Laboratory (Dept. of Construction Management and Industrial Engineering at LSU). The driving software is an interactive, instructional 3D computer-driving simulator (*Driver Education 98* by Sierra Software). Designed for people learning how to drive, it runs on Windows 98 and Windows XP platforms and uses a 3D simulation, which puts drivers behind the wheel for a realistic driving experience. The software is also used by some driving lesson schools (e.g. Folsom Cordova Unified School District-California). The software has over sixty driving scenarios where the participants navigate through a screen projected road conditions with associated road signs and symbols. Driving situations are illustrated with video segments and driving maneuvers inside a virtual city. A voice over instructor leads the driver to the route with specific instructions such as lane changes, turns, merging traffic, stopping at intersections, checking of rear view mirrors, and identification of road signs and symbols. In order to control the simulator, the driver uses interfaces that simulated the actual driving operations. These include foot pedals for accelerator and break with resistance pressure approximating that of an actual vehicle and a steering wheel that responds in real time to driver's maneuvers. However, rear and side view mirrors are activated using buttons on the steering wheel and are projected onto the screen. Figure 3.1 shows a screen capture of a typical road scene from the simulator.

3.2.2. Eye Tracking System

The eye tracking system uses an iViewX lightweight head mounted cameras which capture the images of the subject's eye and field-of-view. This system is manufactured by SensoMotoric Incorporated (SMI, Boston, Massachusetts) and can record numerical data and video protocols. The machine was used to capture fixation control, scan path and distribution, and span of attention. It has options for closely integrated graphical and numerical analysis providing accurate results. The computed gaze position was overlaid on the environment image and visualized in real-time. The integrated MPEG video recording capability was utilized to save the scene video for post-analysis.

Figure 3.1. Screen shot of a road scene projection from the driving simulator.

The eye tracking hardware consists of a lightweight bicycle helmet that is adjustable and well tolerated by all subject groups due to its comfort in wearing while performing the experiments. It carries two adjustable cameras positioned in front of the forehead. The first camera captured the participants' field of view and indicated the relative position of the head. It shows the images where the head is pointed towards to and is usually used to indicate deviations of fixations from the visual screen. The second camera captured the infrared image of the eye. The eye is projected is projected onto a mirror in front oft eye and a camera captures the movement. The iViewX system uses an algorithm to map the captured eye movements. Images of the eye were analysed in real-time with video field rate, resulting in a 50/60 Hz sampling rate. The corneal reflection of the light source (infra-red) is measured relative to the location of the pupil center. Tracking corneal reflexes on the iris together with the pupil compensates shifts of the camera relative to the head. The raw eye movement and pupil diameter data together with the actual gaze position, i.e., as displayed on the monitor, can be synchronized with external stimuli and recorded.

Data is exported into open formats (ASCII or text) and is integrated into graphical analysis in the integrated iViewX software. The software used for eye movement analysis provides graphical images and numerical values of eye movements. The standard iViewX provides interactive analysis functions for image-based stimuli. Objects (i.e., areas of interest) defined were integrated object editor. Interactive analysis allows for changing the permiter of the areas of interests as well as specific time periods for which eye movement measurements can be used. The eye tracking device and driving simulator configurations are shown in Figure 3.2.

3.2.3. Projector

The driving images are projected on a 556.26 centimeters by 416.56 centimeters screen with diagonal width of 695.96 centimeters, through the use of a multimedia projector. The projector is a lightweight, In Focus LitePro$^{(R)}$ 720 with 150-watt-metal halide lamp with frequency response between 10 Hz to 20 kHz. The screen resolution of the projected image is 800 by 600 just as it appears in a computer screen. Screen resolutions between 800 by 600 and 1024 by 768 are compressed to 800 by 600. The distance of the projector to the screen is 30 feet.

Figure 3.2. Head-mounted eye tracking device (top) and driving simulator (bottom).

3.2.4. Digital Video Camera

Two video cameras were used in this study. The first video camera pointed towards the participants and captured the image as they performed the experiment. This video is necessary in order to assess the participant's physical demeanor during the experiment. The second video camera captured a steady video of the visual stimulus which is the projection screen as the participants viewed the visual scene. This video was used to crosscheck the verbal responses of the participants to that of the fixation sequence data. The digital video cameras used in this experiment were two JVC GR – DVL - 9800 with a 200X optical zoom capability.

3.2.5. Computers

Two computers were used in the experiment. The first computer was used to run the driving simulation program and was assigned as the participant's personal computer. It also captured driving performance ratings. A second computer contained the eye tracking system. This was used to run the software that captured and recorded eye movement data. The computer systems used were two Gateway computers with Pentium® 4 Processor, 3.00 GHz at 1.00 GB of RAM.

3.2.6. Cellular Phones

The participants used their own, personal cellular phone in the simulated conversation experiment. This was done to eliminate any unfamiliarity with the operations of a different cellular phone. Two cellular phones were used. The first phone was used by the participants while driving while the second cellular phone was used by another person located in an adjacent room who was assigned to engage the driver participant in a conversation. All cellular phones used were hand held.

3.3. Procedures

The experimental procedure was divided into four parts. These were screening and instructions, practice and calibration, experimental tasks, and post experiment evaluation. The details of the procedures are described below.

3.3.1. Participant Screening and Instructions

Participants were invited to participate in the experiment. Invitations were sent through e-mails and classroom announcements (Appendix A). Each respondent was informed about the nature of the experiment. Each respondent prior to participation in the experiment signed a consent form, explaining the objectives, methods, procedures, risk, and other information pertinent to the study. Background information such as age, driving experience and general physical and mental states were gathered using questionnaires to screen the suitability of participants for the experiment (Appendix D).

A set of criteria was used to exclude participants from performing the experiments. These include, but not limited to, not possessing driver’s license, major visual impairment, headaches and other mental and physical conditions that would prevent the individual in operating the driving simulator while wearing the head mounted eye tracking device.

3.3.2. Practice Driving and Eye Tracking Calibration

At the beginning of every experiment, practice sessions for each experiment and for all driving conditions were performed by the participants to acquaint them on the use of the driving consoles and the simulated driving environment. The practice session also made the drivers get used to driving while wearing a head mounted eye tracking device. After the practice session, a calibration procedure was conducted. Calibration is the process in which the iViewX system establishes the relationship between the position of the eye in the camera view and a gaze point in space, the so called point of regard (POR). The calibration also establishes the plane in space where eye movements are rendered. Since this relationship strongly depends on the over all system set up and also varies between subjects, a reference measurement (calibration) must be performed before each experimental trial. A nine point calibration procedure was conducted using the diagram shown in Figure 3.3.

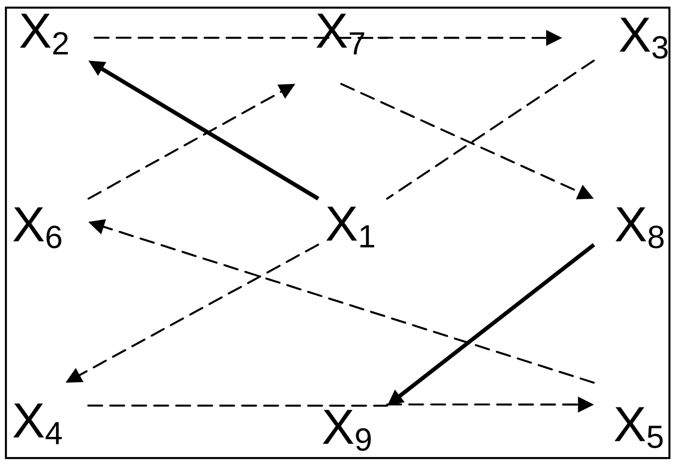

Figure 3.3. Nine-point calibration diagram.

The calibration procedure was done by asking participants to fixate on nine predetermined points on the overhead screen in order to measure pupil and corneal reflex. During calibration, the subject is presented with a number of targets in known locations. The presentation of stimulus was done one at a time using the sequence (from X_1 to X_9) as indicated in Figure 3.3. The location of points encapsulates the perimeter of the screen. Using these reference points, the system creates a mapping function that relates all eye positions to points in the calibration area. The drift correction function of the iViewX system was used from time to time to correct eye for eye drift.

3.3.3 Experimental Tasks

The tasks performed by the participants involved the use of driving simulator, eye tracking with and without distraction. The study was divided into two experiments. The first experiment conducted involved two driving sessions. The participants performed the two driving sessions while wearing the head mounted eye tracking device as shown in Figure 3.4. The driving conditions are described as simple and complex driving. The number of objects I the visual scene as well as the driving maneuvers required of the driver participants differentiate simple from complex driving tasks. Detailed descriptions of the driving conditions are discussed in the specific procedures found in chapter 4.

The second experiment involved driving and distraction. The driving condition used in this session is the complex driving condition. In this session, secondary tasks were added in the form of cellular phone use. The participants were asked to dial a specific number and begin a simulated conversation. The conversation is simulated by a third person asking a series of questions that the participants were supposed to answer. The questions range from a variety of topics designed to simulate normal conversation.

3.3.4. Post Experiment Evaluation

The post experiment evaluation consisted of two survey instruments. The first is a multidimensional subjective workload assessment developed by the National Aeronautics and Space Administration Task Load Index (NASA-TLX) workload assessment. The second survey instrument measures the subjective feedback from participants regarding their perception of safety in driving. The questions on the second survey instrument were designed to be directed towards the experiment conducted that as much as possible eliminate any bias with respect to their real life driving experience.

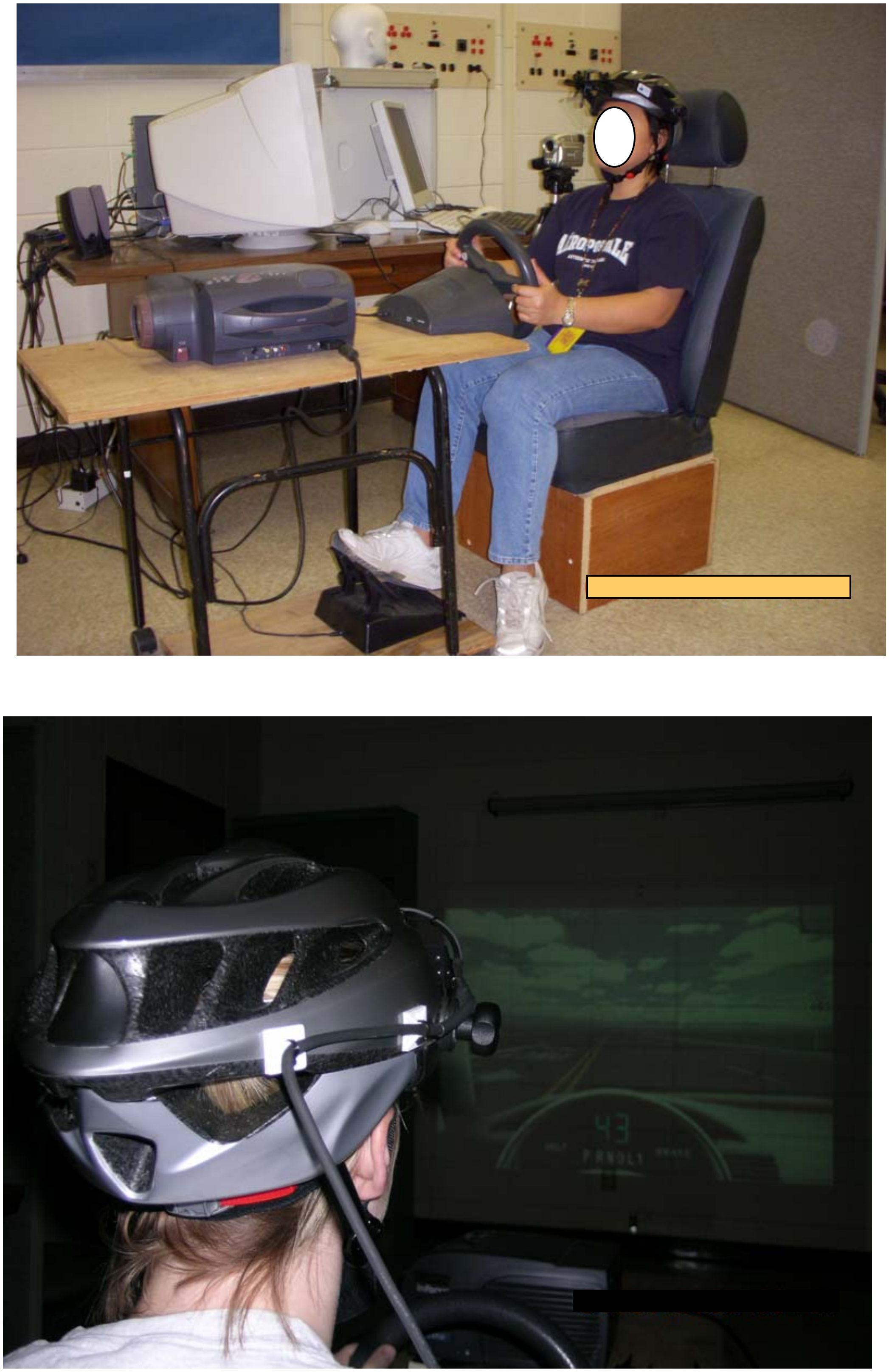

Figure 3.4. Participants operating the driving console while wearing the head-mounted eye tracking device.

At the end of the driving sessions, the participants were asked to evaluate the experimental tasks. Two evaluation instruments were used. The first instrument is the NASA TLX workload assessment method. This method used six factors to evaluate the workload based on factor ratings and ranking. On the other hand, the second survey instrument used is a post experimental questionnaire which asks specific questions to the participants. The main objective of the post experiment questionnaires is to get feedback from the participants with regards to the perception of safety as well as get their overall assessment of the experiment in their own words. Both instruments were described in details in the proceeding sections.

3.4. Design of Experiments

A multivariate analysis of variance (MANOVA) design was used. The analysis of variance (ANOVA) compares whether the mean eye movement data described using the fixation location and frequency of any of the individual experimental conditions differ significantly from the aggregate mean across the experimental conditions. The experimental design was employed to simultaneously evaluate the effect of independent variables. The variables that were evaluated in the experiments are as follow:

3.4.1. Variables

The independent variables used in this study are participants driving expertise and driving conditions. The independent variables are:

- Driver expertise - All participants were grouped (five groups) according to the frequency of driving times per week.
- Driving conditions - Two driving conditions described as simple and complex driving conditions were used.

- Workload – The secondary task provides two conditions, i.e., driving with and without the use of cellular phone.

The dependent variables were used to assess visual behavior and driving performance. The dependent variables were classified into:

- Eye movement – Measurement of eye movement were done using the fixation location, duration and frequency, and gaze, or saccadic path.
- Verbal matches – These are verbal reports of drivers fixation on screen and were measured as a percentage of the total verbal reports
- Driving performance – The performance of drivers are measured based on a set of by errors commonly committed during driving. These are lane crossing (LC), speeding (SP), collisions (C), pedestrian lane crossing (PL), maintaining a safe distance (MSD), and crossing a red light (CRD).

3.5 Methods of Data Collection and Analysis

To meet the objectives of the study, a data collection and analysis scheme was developed. The scheme provides a systematized procedure starting from the grouping of participants, to describing the components of the procedure and what each component enabled the experiment to measures used for analyzing eye movement and driving performance.

3.5.1 Grouping of Participants

The participants were divided into five different groups based their driving experience. The experience level was determined by the frequency of driving per week as scaled by the author. The drivers as listed on table 3.1 were arranged in increasing frequency of vehicle. For purposes of discussion, Group 1 consisted of members who were infrequent users of vehicle and were referred to as the novice or less experienced drivers. On the other hand, group 5 consisted of members who were frequent users of vehicle and were referred to here as the most experienced drivers. Out of the fifty participants, only 38 were considered for analysis. The other 12 participants' data were excluded due to certain inability to establish "good" fixation. These errors may be attributed to the system as well as to the participant. Such occurrences of errors vary for different individuals and may be attributed to the following reasons:

(a) inability to calibrate and standardized the eye tracking system due to certain facial features which may include but not limited to the shape of the eye and thickness of eyebrows;

(b) inability to perform the driving task completely (< one minute of driving);

(c) eye-tracking system error for which the author have very limited control for example no video of the driving scene recorded; and

(d) unusual discrepancies and errors in fixation data due to the displacement of the head mounted eye tracking device while performing the driving tasks.

Table 3.1. Participants' groupings based on frequency of driving.

Group #	Frequency of driving (times /week)
1	At least once
2	1 – 2
3	3 – 4
4	5 – 7
5	> 7

3.5.2 Data Collection Methodology and Architecture

The different components of the methodology are summarized in Table 3.2. The components are eye tracking, experimental protocol, experimental tasks, and results analyses. These components methodically enabled the experiments to be conducted. A data collection architecture shown in Figure 3.5 was developed in order to systematically account for the inputs from the different components that were necessary in the eye movement and driving performance analyses.

The components of the table were used with the schematic diagram of the data collection. Using the schematic diagram shown in Figure 3.5, eye movement data such as fixation characteristics and saccadic path were collected from the eye tracking software as recorded from the computer system. The data comes in the form of graphical and numerical data (Appendix E). The driving performance ratings on the other hand were gathered from the performance ratings provided by the driving simulator. The data comes in the form of frequency of errors committed. Only the six errors identified previously were of particular interest in the experiment. Verbal responses were also recorded. Cross-referencing using videos and time stamps provide side-by-side analysis of eye movement measurement, driving scene evaluation, and driving behavior (lane change, speed, object identification etc.).

Scene identifications were selected based on the particular driving scenario that was used. However, the four areas of interest were the same for all driving scenarios. The four areas that are of interest encompass the entire visual scene. Quantification of data, using fixation and saccadic path, was based on the specific areas of interest. Subsequent analyses using gaze path, pictorial, and other visualization analyses provide a rich representation of the visual behavior and user driving performance. A separate video tape of the screen projection and the participant were also collected. The recorded videos were used for the verbal matching and object identifications for cross referencing with visual fixations.

Table 3.2. Overview of methodology.

Component	Contribution
Eye tracking	Get gaze positions and scan path Calibrate visual scene Define regions of interest Define pertinent scene elements
Experimental Protocol	Define experimental variables Define driving scenarios Design verbal response Specify the way experiment should go
Experiment	Perform test
Results analysis	Define systematic methods for eye tracking Analyze results of feedback questionnaires Improve experimental protocol

3.5.3 Match Rates of Verbal Reports and Eye Fixation

Match rates were collected from the verbal reports of the driver, video of their driving performance and fixation data. In this scenario, the participants were asked to verbalize the specific image for which they are fixating at any given time while driving. There is no specific format for the verbal reporting. Similar to the "free mumbling format" used by Hayashi (2005). In this format, the participants freely used their own words to describe, identify and report the current objects that they are looking at. Match means right verbal response at right fixation at right time. Each verbal report is a match if the estimated visual fixation is within plus-minus one second (± 1 second) of the time of report coincided with the task of the verbal report. Hayashi, (2004) used the plus-minus one second rule in analyzing verbal reports and visual fixations of pilots. A time allowance was adapted in this experiment in consideration of the inaccuracy of coincidence of the time point of verbal reports and the fixations. This buffer was based on the natural assumption that there are delays in the driver's verbal response due to their internal information processing as well as due to the difficulty to pinpoint exactly when the verbal report started from the video records thus covering potential margin for experimenters errors.

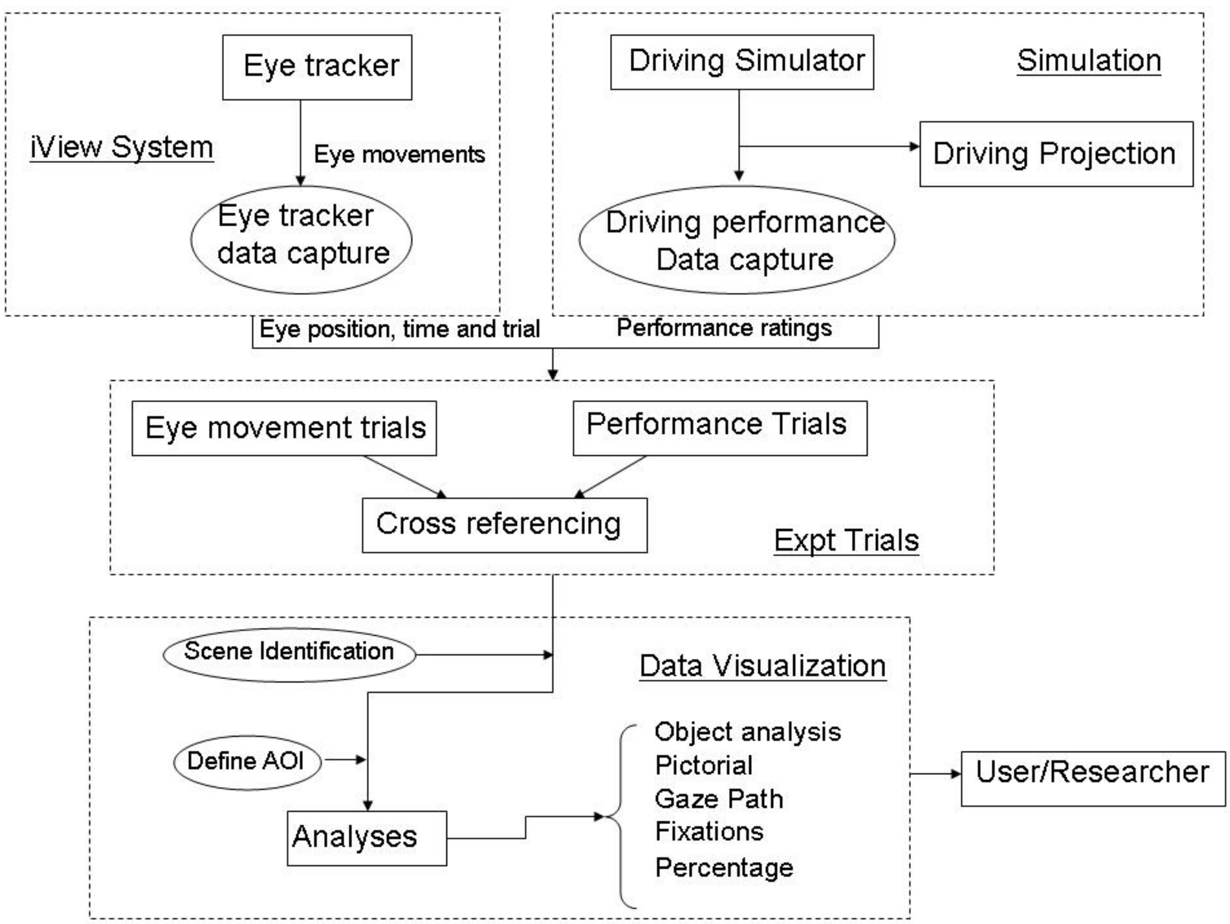

Figure 3.5. Schematic diagram for data acquisition.

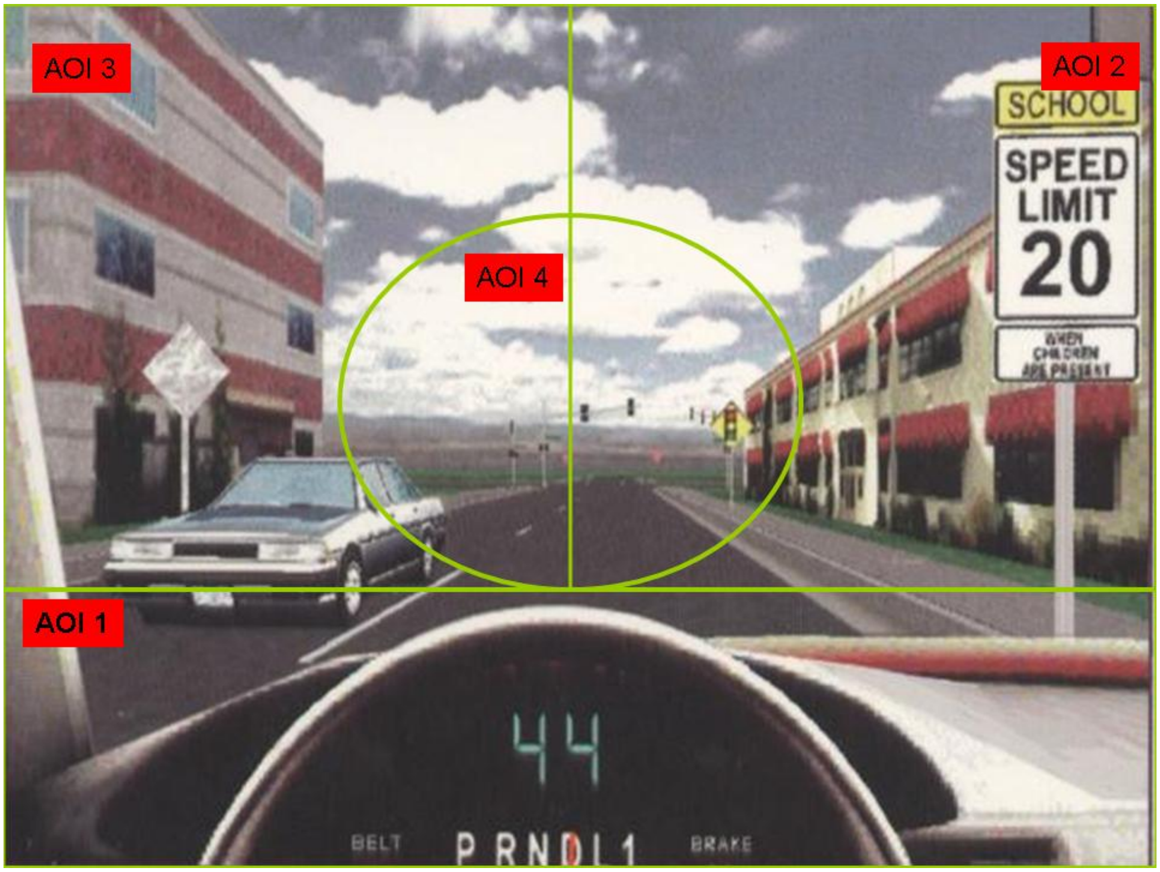

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Figure 3.6. Area-of-Interests selected (AOI 1 – Dashboard Area; AOI 2 – Left Side View; AOI 3 – Right Side View; AOI 4 – Front and Center View).

3.5.4. Areas of Interests in Visual Scenes

An outline of the display as well as the driver's view is shown in Figure 3.6. The view is divided into four areas of interest in order to monitor the visual tasks that drivers perform while operating the vehicle. In the driver's view of the road, the first area-of-interest (AOI 1) is the dashboard area. This area is the status-tracking panel containing the odometer that displays the speed of the vehicle, the turn signal, right and left blind spot mirrors and gear status. The second area of interest (AOI 2) was assigned to the (AOI 3) provides a view of other vehicles coming in the opposite direction as well as centerline that divides the road. Both left and right areas of interests also give a view of the cross intersection traffic which is very useful when turning. In addition to the three areas of interests, a fourth area (AOI 4) was assigned to monitor the center view which is an important viewing task. This area will usually enclose the traffic lights, vehicles in front as well as for maintaining of lane course and distance from other vehicles. This critical view provides visual assessment of overall driving status and is most commonly used in normal driving.

CHAPTER 4

EXPERIMENT 1:
EVALUATION OF DIFFERENCES IN VISUAL BEHAVIOR OF DRIVERS

4.1. Introduction

In describing the human visual behavior, the use of subjective methods to assess workload and situation awareness is a complex process that involves elicitation of interactions between users and technology. Results of studies obtained from subjective methods are usually based on cognitive models that incorporate assumptions thus limiting their applications. In order to improve the understanding of visual behavior, quantitative methods of assessment have been developed. Specifically, the use of eye movement as objective inputs can augment subjective feedback. Visual patterns are valuable inputs in different types of tasks. Driving is a particular task where analysis of visual behaviors through eye movement tracking can help better understand how different factors affect individual performance.

As one may have observed on the road, different drivers have different levels of agility of eye movement. Some spend more time looking at controls while others spend time on external surroundings. Of the different modes of transportation driving has some unique characteristics compared to piloting an airplane, operating a train or boat/ship. In driving, the visual scene is very dynamic in driving with successive movement of objects often without significant association with each other. The number of objects in the visual scene per time interval or density of objects on the road scene affects drivers' behavior in as much as it competes for the drivers' visual attention (Sodhi, et al., 2002). When attention allocation is limited, it is conceivable that the risks of vehicular accidents are more likely. The dynamism is clearly observed in gaze behaviors of drivers. For example, while drivers concentrate on looking in front of the car, other drivers concentrate on the road as they quickly shift their attention frequently on objects passing by. These observations have been established by studies conducted by Fitts, et al., 1950 as cited in Hayashi, 2003 in the earliest and largest eye movement study for pilots. In their study, the object scanning pattern differences were investigated for pilots of different levels of expertise.

The observations of Fitts, et al. (1950) may also be extended to road based vehicular transportation. For example, one driver can make a certain number of fixations per minute on the dashboard while another driver will hardly use this panel at all. Some drivers emphasize response to road objects while others emphasize response to speed control. While this may be simply due to different scanning speed of individuals, the different fixation frequencies may reflect more basic control strategy differences. Different drivers produce different search strategies as concluded in a study by Crundall, et al. (1999). Drivers who frequently use their vehicle produce a search pattern different from that of the infrequent users. For an experienced driver, scanning the visual scene may be automatic as compared to the less experienced driver.

In studies dealing with eye movement vis-à-vis driving tasks, one must establish that although personal scanning behavior or control strategy differences are important to understand, it does not, however, directly indicate differences in visual object recognition. The complexity of information required for the driver to process brought about by the increase in number of objects in the visual scene limits their ability to visually capture the objects, whether through direct or peripheral vision. Such limitations and constraints provide a critical condition that might eventually affect the driving safety and performance. The objective of the first experiment was to determine the changes that occur in visual behaviors for drivers with different level of expertise at different driving conditions. Using the eye tracking technique, it was also the objective of the study to determine the reliability of eye movement measurement. This provides for describing the association of objective measures and subjective feedback in explaining visual attention and cognitive perception. To meet the objectives of this study, a simulated driving experiment was conducted with the following hypotheses:

H_1: When performing a driving task, the existence of scanning differences for different individuals affects visual object recognition.

H_2: As the number of road related objects increases, the time spent on different areas of interest in the visual field decreases.

To describe visual behaviors, eye movement was measured in terms of eye fixation patterns, frequency and gaze or saccadic path. Fixation location is any position of the eye at a specific point and at a specific time on the visual stimulus. The frequency of fixation is the amount of fixation located in specific areas of interest at preset duration. Duration is the length of fixation location and is measured using a preset time duration criterion. Fixation pattern describes the time series location of fixation points. On the other hand, saccades are paths made up of quick jump of fixation from one location to another. Driving performance was evaluated based on a pre-specified driving violations.

4.2. Experimental Tasks

The first experiment consisted of two driving tasks. Both tasks involved simulated driving while wearing the head mounted eye tracking device. Participants performed the two driving sessions using the simple and complex driving conditions. The simple driving condition is a sign and symbol identification task that simulates a basic driving scenario incorporating a city-like driving. On the other hand, in the complex driving condition, the driver had to assess risks and take proper actions to avoid vehicular collisions. Drivers were presented with reckless drivers on the road as well as with more road signs and symbols to identify. The complex road condition required each driver to perform intricate defensive maneuvers to avoid road collisions. The participants were also asked to perform driving maneuvers wherein it is necessary for them to consider all aspects of the road before executing the tasks. With the use of the control interfaces, the participants were asked to drive and to identify symbols as instructed by the simulator.

While driving, the participants were also asked to verbalize the objects in which they were currently looking at. They were particularly instructed to locate signs and symbols that are deemed important during the performance of the driving task. They were instructed to follow a verbal protocol report wherein they could use the words of their choice in their verbal report. A video and audio of the driving event as well as the driver's verbal annotations of the objects were recorded. Each driving session lasted for five minutes in which eye movement and driving performance data were collected.

4.2.1 Description of the Driving Conditions

The visual driving scene and the monitoring tasks that drivers were expected to perform during the duration of the driving phase were outlined in this experiment. A list of events at specific driving elapsed time is shown in Table 4.1. They were compiled after carefully reviewing the video and a critical observation of the driving condition. The two simulated driving conditions used the same driving path and with similar occurrence of driving and task sequences.

Table 4.1. Critical monitoring task sequence.

Approximate Driving Elapsed Time (min:sec)	Critical Events	Actions Required
00:00	Engine Start up sequence	Dashboard control: Belt light off, shift status to drive
00:07	Merge traffic	Vehicle prepares to merge traffic. Look at left side mirror for other vehicles, activate left turn signal, initiate merge
00:10	Drive (35 mph)	“Minding the store”. Check speed (tachometer), maintain lane
00:13	Approach city area	Check speed and vehicles in front
00:20	Approach First intersection	Reduce speed
00:21	Stop at 4 way Stop sign	Gently step on break and view cross mirror before turning
00:42	Drive	Continue driving
00:48	Approach second intersection	Reduce speed; stop on red lights
1:02	Right turn	View cross mirror, right side mirror, activate right turn signal
1:58	Continue driving (45 mph)	Continue driving, increase speed
2:10	Change to left lane	View rear and left view mirrors, activate left turn signal
2:13	Approach intersection	Reduce speed
2:21	Stop at stop sign	Step on break gently to complete stop
2:30	Turn left	Steer left
2:34	Drive (35 mph)	Continue driving, maintain right lane
2:47	Approach intersection	Reduce speed
3:14	School zone	Watch out for pedestrian crossings
3:25	Negotiate curve	Check Mirrors and lane
3:46	Slow down, Drive at 20 mph	Maintain speed at 20 mph
4:05	Approach T-intersection	Prepare to stop
4:15	Turn right	Stop, check mirrors, activate right turn signal
4:31	Drive (35mph)	Continue driving, check speed
4:18	Curve negotiations	Check lane and side view mirrors
4:49	Reduce speed, Approach pit stop	Reduce speed
5:00	Park at pit stop	Activate right turn signal, steer to pit stop; press brake gently to stop

A significant difference of complex driving to that of simple driving is that in the former, there is a requirement for some defensive maneuvers from the drivers. There was also the presence of more vehicles with some simulating reckless driving behaviors, pedestrians crossing the streets, and more road signs and symbols that necessitated critical maneuvers to avoid any accidents. It should be noted that, in driving there exist no standard protocol describing the order of monitoring objects, hence no eye movement can be inferred from the critical monitoring tasks. The list serves only as a guide to study the critical events occurring during the duration of the driving. The eye movement path recorded will determine the actual eye movement of the drivers.

4.3. Evaluation of Visual Behaviors

In order to characterize the visual behavior of drivers using eye movement measurement, three parameters were analyzed. These are: (1) fixation pattern; (2) frequency of fixation based on total driving elapsed time; and (3) saccades. The results are presented in three sections, each corresponding to the parameters stated. Finally, results of the verbal match are also shown as the last section. The verbal match is an important parameter that was used to evaluate differences in fixation and actual visualization of objects by participants.

4.3.1. Comparison of Eye Fixation Patterns

Fixation sequences from all participants were collected using the iViewX software. The software allows for pictorial and time analysis by plotting gaze path and fixations on scene image or video. This software provides two streams of statistical data. The first is associated with eye movements such as saccades, while the second is associated with the fixation behavior on objects in the participant's field of view. The intersection of the participant's point of regard (POR) and the display surface were used to analyze fixation data defined by location and time. The IviewX eye tracking system records the intersection using circles to represent fixation location. The diameter of the circle also represents the duration of the fixation. The lines connecting the circles are saccadic jump and a continuous jump represents the path.

A pictorial representation of the fixation pattern is shown in Figure 4.1. The image is divided into four areas of interests as described previously. However, this image is only a snapshot and was used to illustrate a pictorial view of the fixation path. No valuable information can be extracted from the image as it shows eye movement on only a specific segment of time and not the entire task duration.

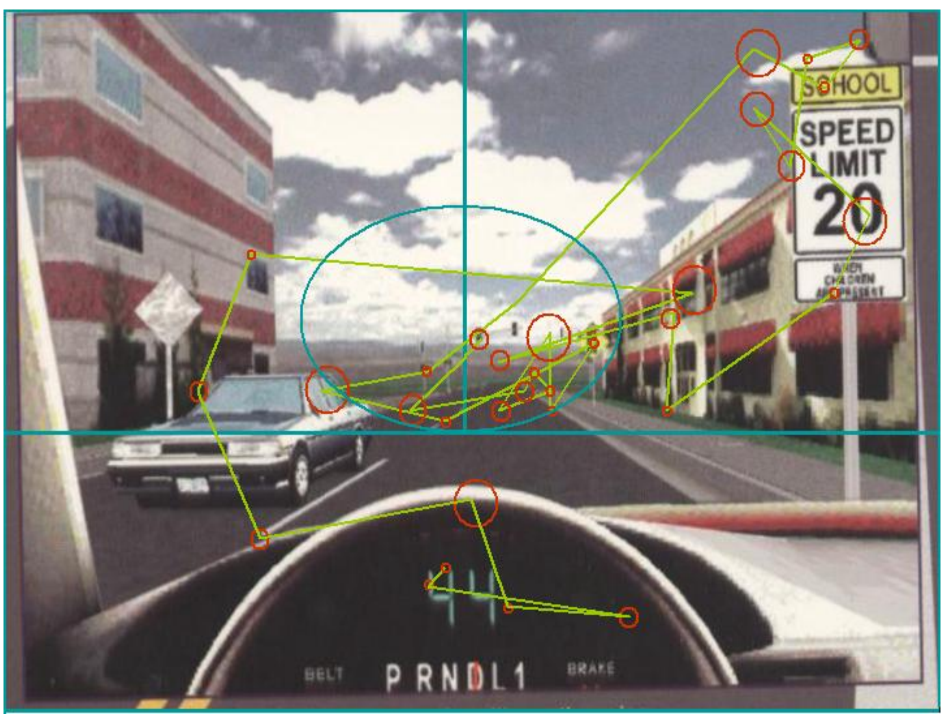


Figure 4.1. A snapshot of the fixation patterns of a participant.
(Note: saccades for small fixations were omitted from the image).

Fixation time on specific areas-of-interests (AOIs) is defined as the total time spent within the boundaries of the AOI. The system allows for specification of fixation criteria. In this regard, the criterion used for consideration of fixation was 1.0 second per radius (Hayashi, et al., 2005). Longer durations were designated as multiple fixations. A longer fixation shown by longer radius correlates to the number of fixations. For example, a two-second radius was considered as two fixations. In the analysis of raw eye movement, the patterns of fixation were determined using the data from the eye tracking software wherein the eye movement data were reduced to fixation that satisfied the fixation criteria. Saccades were also eliminated by omitting points where the running averages of the intersections failed to meet the criteria. Each fixation was assigned to an area of interest based on its location and duration. Fixation location was taken from the statistical mode of location for the different groups. The locations were recorded based on the areas of interest defined earlier. These locations were 1 for AOI 1 (dashboard area), 2 for AOI 2 (right side view), 3 for AOI 3 (left side view) and 4 for AOI 4 (front and center view).

A fixation pattern for one driving session is shown in Figure 4.2. It provides a picture of the patterns of eye movement by recording the location of the fixations for each specifically defined areas-of-interest. Plotted on a time series scale, the path threads the sequence of eye fixation for the duration of the simple driving task. To illustrate the comparison of fixation sequences, three segments consisting of thirty seconds of driving elapsed time were selected. Fixation locations were recorded for each segment and for each group for the two driving conditions. The locations of fixation points obtained for the simple driving condition are summarized in Table 4.2.

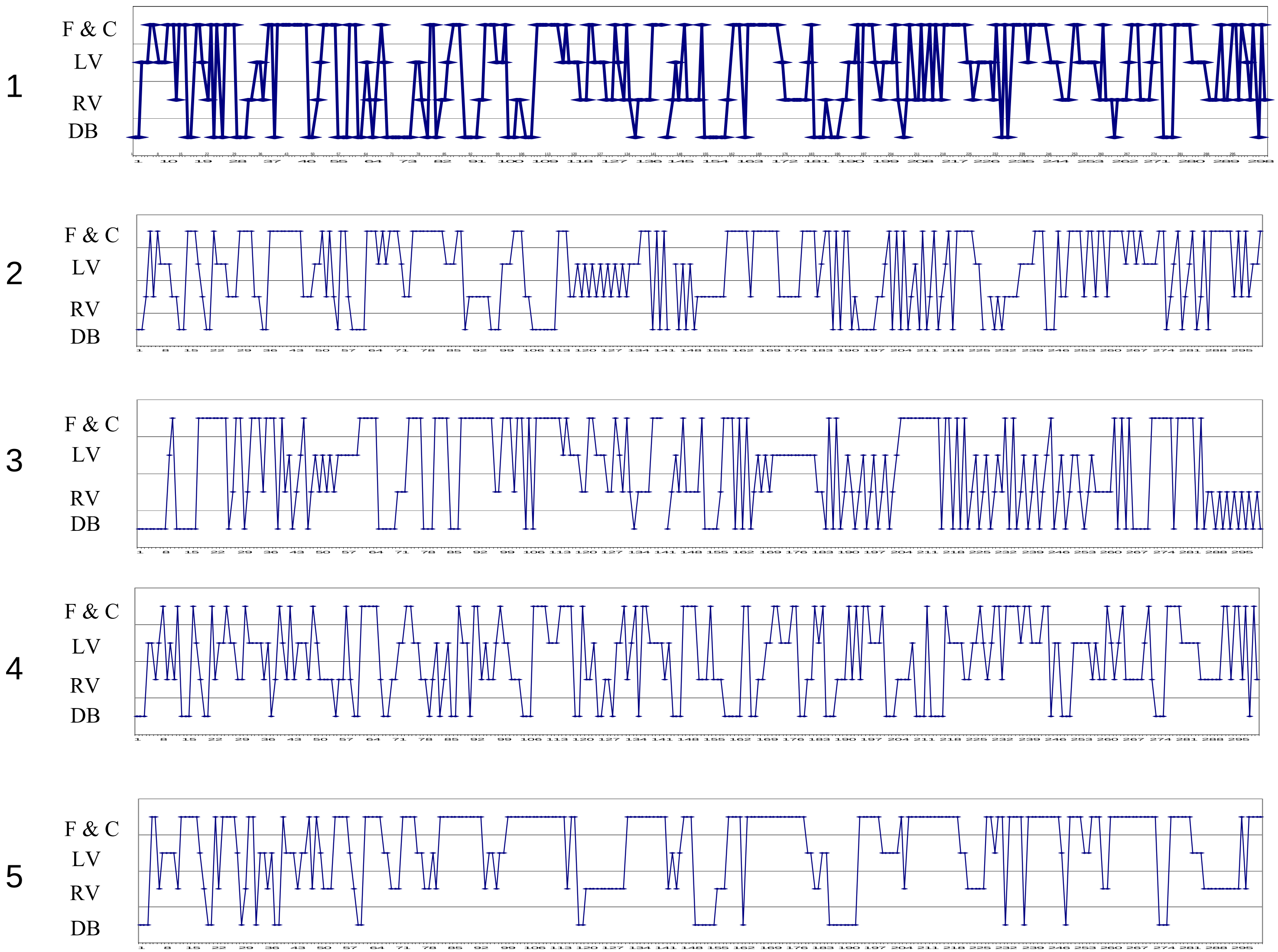


Figure 4.2. Fixation sequences for the five groups of drivers during the five-minute driving (F&C = front and center view; LV= left side view; RV= right side view; DB=dashboard view).

Table 4.2. Location of fixation point obtained for the different groups of drivers during a 30-second simple driving session [1= AOI 1 (dashboard area); 2=AOI 2 (right side view), 3= AOI 3 (left side view); and 4=AOI 4 (front/center view)].

Elapsed Time (sec)	Fixation Locations or AOIs				
	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
1	3	4	2	1	5
2	1	1	1	1	1
3	1	1	1	1	1
4	1	1	2	3	1
5	1	3	4	3	4
6	1	3	2	4	4
7	1	2	4	4	2
8	1	3	3	3	3
9	1	4	3	3	3
10	3	2	3	3	3
11	4	3	2	4	3
12	1	2	2	4	2
13	1	4	1	2	4
14	1	1	1	4	4
15	1	1	4	4	4
16	1	1	4	1	4
17	1	4	4	1	4
18	4	3	3	4	3
19	4	2	2	4	2
20	4	1	1	3	1
21	4	1	1	2	1
22	4	4	4	4	4
23	4	2	3	1	2
24	4	3	3	4	4
25	4	3	3	1	4
26	1	4	2	4	4
27	2	3	2	4	4
28	4	3	2	4	3
29	4	2	4	1	1
30	1	2	4	1	2

An analysis of variance was performed to determine the differences on the average fixation location for the five groups. This was done in order to determine the sensitivity of the results with respect to the assignment of participants to each group as well as the division of groups based on the frequency of driving criteria. The results are tabulated in Table 4.3.

Table 4.3. Results of analysis of variance of fixation location of the five groups.

Source of Variation	SS	df	MS	F	F crit
Between Groups	528.37590	4	132.09398	2.301895	2.29
Within Groups	8320.8076	145	57.38488		
Total	8849.1835	149			

The analysis of variance shows that the mean fixation locations of the five groups are different ($F_{calculated} = 2.301 > F_{tabulated} = 2.29$). The $F_{calculated}$ is just slightly higher than the $F_{critical}$ suggesting that the differences are subtle. A multiple comparison method using the Tukey-Kramer (T-K) analysis was used to look for specific differences between combinations of groups. The T-K analysis allows for the identification of differences in means of the individual groups as well as combinations of groups. Table 4.4 shows a summary of the T-K results.

As can be seen from the T-K groupings, groups 1, 2 and 3 are not significantly different. The same is true for groups comparing 3 and 4, and groups comparing 4 and 5. Given these results, five other combinations were compared. These are groups 1 and 2, 2 and 3, 3 and 4, 4 and 5, and 1, 2 and 3. The results of the combination of groupings show that a combination of groups 1 and 2 are not different from a combination of groups 2 and 3. In the same manner, combination of groups 2 and 3 are no different from a combination of groups 3 and 4. However, there were significant differences in mean fixations found between combination of groups 1, 2 and 3 with that of combining groups 4 and 5. Significant differences were also found between groups 1 and 4 and between 4 and 5. A combination of groups 1, 2 and 3 is different from a combination of groups 4 and 5.

Table 4.4. Summary of different combinations of groups and the sensitivity of differences in variances at $\alpha = 0.05$. (Note: Similar T-K letters indicate no significant differences in means.)

Individual and Combined Groups	Mean Fixations	T-K Groupings
1	71.9	A
2	77.8	A
3	78.7	A,B
4	92.6	B,C
5	97.3	C
1 and 2	74.85	A
2 and 3	78.25	A,B
3 and 4	85.65	B,C
4 and 5	94.85	C
1,2 and 3	76.13	D

The results suggest that the frequency of driving used as the method for assigning groupings has a strong basis for comparing groups 1, 4 and 5, which are from least experience to most experience drivers, respectively. On the other hand, the groups that were partitioned in the between the least and most frequent vehicle users per week, i.e. groups 2, 3 and 4, do not show significant differences in terms of fixation means. Based on these statistical analyses, the individual differences; therefore, were evident only between the first group and the fifth group. As such, the discussion of the results is limited to comparing the infrequent vehicle users to those of frequent vehicle users. The conclusions are also based on the infrequent vehicle users and the frequent vehicle users or groups of drivers. However, results of fixation location, frequency and saccadic path for all the groups are still presented in the discussion for trending and visual behavior comparisons.

The fixation locations in Table 4.2 were plotted for each group for the simple driving condition as shown in Figure 4.3. The plots in this figure show sequence of fixation for each group based on the four areas of interest defined previously. The saccades from one area to another are shown as a time series line for the five-minute duration. A comparative ocular inspection alone would show that there exist different fixations for the same areas of interest at a particular time. Also, the results show an effective collection of fixation data as there are very little gaps or breaks from the fixation lines for all groups. Experience level increases from the first group (infrequqnt vehicle users) to the fifth group (frequent vehicle users). Results obtained for the fixation patterns of each group were compared with the results of fixation patterns for the fifth group. Each fixation of the groups (from 1 to 4) was compared with the results of fixation patterns for the fifth group at specific driving elapsed time. In the comparative analysis, matches of fixation between the groups were determined. A match was defined as fixation located at the same AOI at the same time. A match was recorded as zero (0 – no difference) and a mismatch was recorded as negative one (-1). The total number of matches is then divided with the total number of comparisons or driving time (i.e., 30 seconds) to give the percent match as given in the equation below:

$$\text{Percent Fixation Match} = \frac{\text{Number of similar fixation point}}{\text{Total number of fixation points}} \times 100$$

For the five-minute driving duration, three segments were selected for matching. These segments are from 0 to 30 seconds (start segment), and 150 to 180 seconds (middle segment) and from 270 to 300 seconds (ending segment). Results are tabulated as a mean

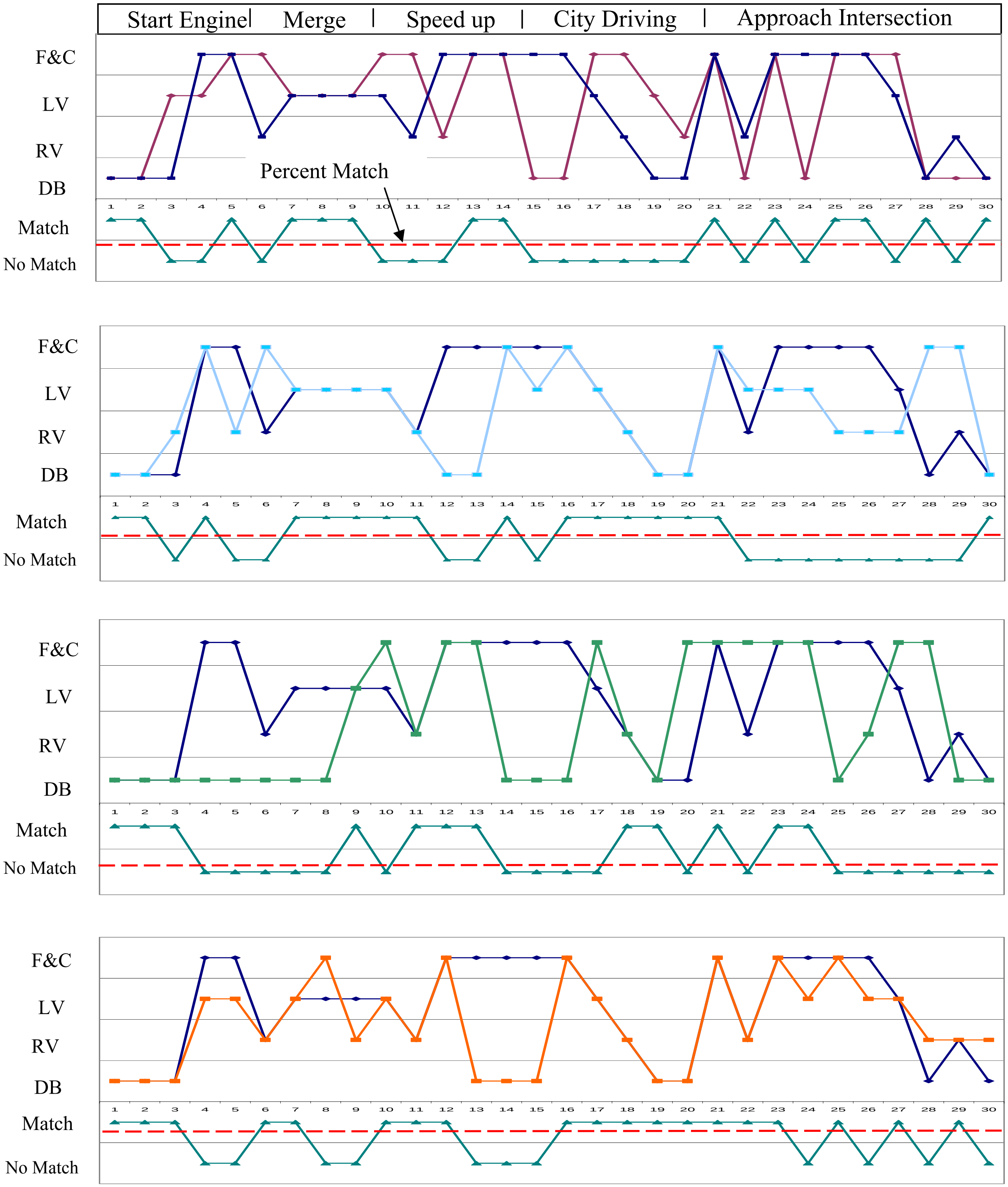


Figure 4.3. Comparison of fixation patterns of Groups 1, 2 ,3 and 4 with Group 5 during the first 30-second of simple driving session (Match and non-match between groups are shown as lines; percent matches are shown as broken lines).

percentage matches for the groups and are shown in Table 4.5. From the table, we can see that group 4 has the highest percentage of match with group 5, in terms of fixation location at specific driving elapsed time. For the selected thirty-second segments, group 4 has 63% match for the first 30 seconds, 71% for the middle 30 seconds and 68% for the ending 30 seconds of driving. On the other hand, group 1 has the lowest match with 47%, 32% and 28% for the three segments selected, respectively. To elucidate further, fixation patterns from Table 4.2 and percent matches from Table 4.5 are shown graphically using a time series plot in Figure 4.3. Four plots were shown comparing the patterns of fixation for groups 1 to 4 to that of group 5 during the first 30 second segment. Matches between groups compared are also shown at the bottom of each plot. The total percent match is shown as a horizontal line.

Table 4.5. Mean matches (%) of fixation patterns between Groups (1, 2, 3, 4) and Group (5) for simple driving condition.

Time Interval (seconds)	Mean matches (%)			
	Group Numbers (Driving Experience Level)			
	1	2	3	4
0 - 30	47	53	40	63
150 - 180	32	49	49	71
270 - 300	28	31	61	68

A multivariate analysis of variance (ANOVA) between and within groups was used to compare the fixation matches. The results of the statistical analysis are shown in Table 4.6. The summary of the statistical analysis show that there are significant variations of matches between the four groups for the three segments selected. Though the differences vary, the degree of variations can also be seen as indicative of the differences in matches as the driving elapsed time progresses.

Table 4.6. Summary of ANOVA for simple driving condition.

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	1608.666667	3	536.2222	5.876408	0.020225	4.066181
Within Groups	730	8	91.25			
Total	2338.666667	11				

Since the $F_{critical}$ is less than the $F_{tabulated}$ (i.e., 4.066181 < 5.876408), the null hypothesis that there are no differences among the means is rejected. The analysis of variance shows that there are significant differences between the different groups of driver. A Tukey-Kramer (T-K) multiple comparison tests was performed to identify the means that are significantly different. The results of the T-K multiple comparisons are shown in Table 4.7. The table shows the Tukey-Kramer groupings wherein the means of the groups with the same letter are declared to be not significantly different.

Table 4.7. Summary of Tukey-Kramer multiple comparison of means for driver fixations at simple driving condition (Means with the same letter are not significantly different).

Alpha = 0.05
Critical Value of Studentized Range = 3.85
Minimum Significant Difference = 9.50

Group Number	Mean	T-K Grouping
1	35.67	A
2	44.33	A,B
3	50.00	B
4	67.33	C

The results of the multiple comparison show that the fixation of group 1 as compared with 2, and group 2 as compared with 3 are not significantly different. However, fixation comparisons between group 1 with 3 and 4 are significantly different. Likewise the fixation of group 3 is significantly different compared to group 4.

For the case of the complex driving, the results of fixation location and matches are shown in Table 4.8 and 4.9 respectively. Similarly, the fixation patterns are illustrated in Figure 4.4 with the corresponding matches shown below the fixation patterns. The same method of analysis of variance done for the simple driving condition was done for the results of the fixation results in the complex driving condition.

Table 4.8. Location of fixation point obtained for the different groups of drivers during a 30-second complex driving session [1= AOI 1(dashboard area) 2= AOI 2 (right side view); 3= AOI 3 (left side view); and 4=AOI 4 (front/center view)].

Elapsed Time (sec)	Fixation Locations or AOIs				
	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
1	3	4	1	1	3
2	4	4	3	2	4
3	4	3	2	2	3
4	3	3	3	4	1
5	2	4		3	4
6	1	1		1	2
7	3	2	3	3	1
8	2	3	1	1	2
9	1	1	4		2
10	1	4	4		2
11	1			1	3
12	1			2	2
13		1	1	4	2
14		1	1	3	1
15		4	2	4	3
16		4	4	1	4
17		3	2	2	4
18		2	2	1	3
19		3	2		3
20		2	2	2	2
21	2		4	4	2
22	4	1	3	3	1
23	4		2	1	4
24	2	3	4	3	2
25	4	3			4
26	4	3	1	4	3
27		1	2	2	2
28		2	3	3	4
29		1	1	2	1
30	4	2	4	4	4

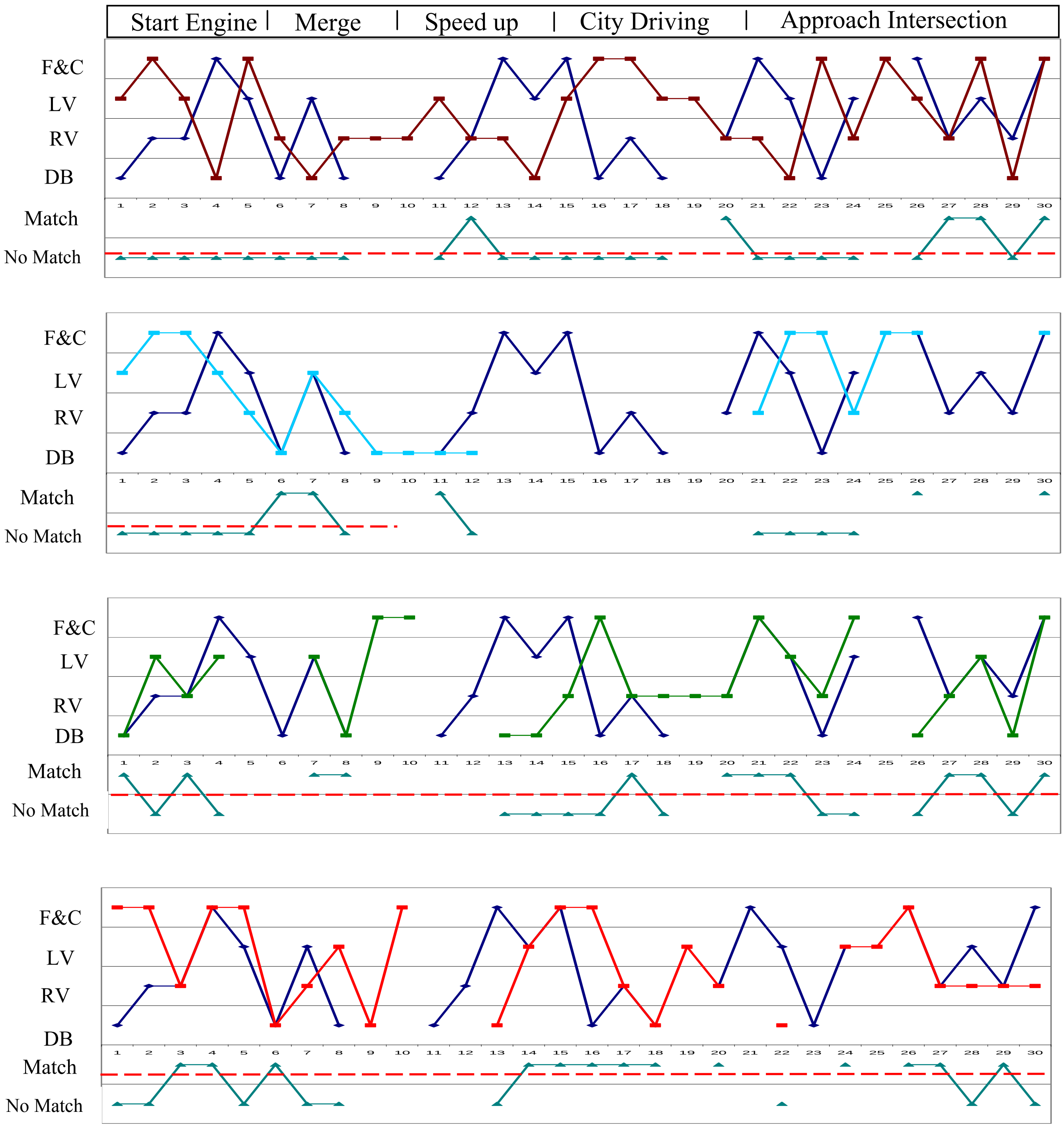


Figure 4.4. Comparison of fixation patterns of Groups 1, 2 ,3 and 4 with Group 5 during the first 30-second of complex driving session (Match and non-match between groups are shown as lines; percent matches are shown as broken lines).

Table 4.9. Mean matches (%) of fixation patterns between Groups (1, 2, 3, 4) and Group (5) for complex driving condition.

Time Interval	Group Numbers (Frequency of Driving)			
	1	2	3	4
0 - 30	19	31	20	59
150 - 180	10	24	27	62
270 - 300	15	12	45	65

In contrast to the simple driving condition, the results for the complex driving condition show gaps or discontinuities in the fixation lines as shown in Figure 4.4. These gaps are events of no measured or detected fixations. Two major reasons for the occurrence of these events may be attributed to the eye tracking system and the visual screen boundaries. For the eye tracking system, there is the possibility of loss of tracking of eye movement by the system due to blinks of long durations, and movement of the head mounted device. Since the eye tracking machine uses a measurement based on the calibration process, any movement, slight or otherwise, would lead to error in measurement or total loss of eye tracking. In a similar observation, the loss of eye measurement may be attributed to fixation beyond the perimeter of the visual screen. Thus, the eye tracking system will not measure any eye fixations outside this perimeter.

For the complex driving condition, despite the gaps in fixation, some similar results were obtained. It can be observed that there is an increasing trend in fixation matches as the frequency of driving level increases. The comparison of each of the four groups to that of group 5 supports this observation. Group 1 has the lowest matches ($F_{(2,27)} = 3.28$, $p<0.05$), while group 4 has the highest matches ($F_{(2,27)} = 1.94$, $p<0.05$) for the three selected 30-second driving segments. Higher variations were observed owing to the inequality of fixation numbers recorded as well as the degree of discontinuity of the fixations for the five groups.

An analysis of variance was performed to compare the mean fixations of the different groups. Table 4.10 shows a summary of the ANOVA for the mean fixation of drivers using the complex driving condition. Since $F_{calculated}$ is greater than $F_{critical}$ (i.e., 17.98573 > 4.066181), it can be concluded that there are significant differences between the groups who performed the driving condition.

Table 4.10. Summary of ANOVA for complex driving condition.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3884.916667	3	1294.972	17.98573	0.000648	4.066181
Within Groups	576	8	72			
Total	4460.916667	11				

To identify the differences among means, the Tukey-Kramer (T-K) multiple comparison test was also performed for the results of fixation matches for complex driving conditions. The results of the multiple comparison tests are summarized in Table 4.11. Means of the same letter are not significantly different.

Table 4.11. Summary of Tukey-Kramer multiple comparison of mean fixations for complex driving condition.

Alpha = 0.05 Critical Value of Studentized Range = 3.85 Minimum Significant Difference = 8.43		
Group Number	Mean	T-K Grouping
1	14.7	A
2	8.34	A, B
3	30.67	B
4	62.00	C

4.3.2. Analysis of Percentage of Total Fixation of Drivers

The second analysis conducted to describe the visual behavior of drivers is the total fixation analysis. The total fixation analysis was determined from the amount of fixations for each area of interest, expressed as a percentage of the total fixations generated by the participants. In contrast to fixation pattern analysis, the total fixations were analyzed without regards to specific time and event in the driving situation.

The total percentage was computed for each area of interest as the amount of time of valid fixations (fixation criterion is 1.0 second) divided by the total driving durations (5 minutes). Tables 4.12 and 4.13 give a summary of the values of percentage total fixations for each group in the four areas of interest for simple and complex driving conditions respectively. Figures 4.5 and 4.6 show the distribution of fixation for the five groups of drivers.

Table 4.12. Percentage of total fixation determined for each of the different areas of interest (AOI) during the simple driving session.

	AOI 1	AOI 2	AOI 3	AOI 4
Group 1	52	13	17	18
Group 2	33	25	20	22
Group 3	24	30	20	35
Group 4	15	23	24	38
Group 5	9	30	20	41

Table 4.13. Percentage of total fixation determined for each of the different areas of interest (AOI) during the complex driving session.

	AOI 1	AOI 2	AOI 3	AOI 4
Group 1	39	20	12	29
Group 2	23	21	23	33
Group 3	21	24	31	24
Group 4	13	28	27	31
Group 5	7	30	25	38

A multivariate analysis of variance was performed to determine any over all effects of driving experience, driving condition and areas of interest and their interaction on total percentage fixation. Table 4.14 summarizes the results of the analysis of the interactions of the three factors. As shown in the table, there are significant effects of groups, condition and areas of interests. The analysis of variance also indicates a slight significance with respect to the interaction of the three factors. No further test was conducted to determine the interaction effect if the three factors as the results show only a slight significance

Table 4.14. Summary of multiple analysis of variance for the total percentage fixation as dependent variable at $\alpha = 0.05$ (S – significant; NS – not significant).

Source	**DF**	**SS**	**F**	**Pr > F**	**Effect**
Group (Experience)	4	0.02685	2.98	0.0190	S
Condition	1	0.53170	3.75	0.0294	S
Group*Condition	4	0.00079	1.34	0.0843	NS
Areas of Interest (AOI)	3	0.07925	3.20	0.0001	S
Group*AOI	3	0.54318	5.43	0.0645	NS
Condition*AOI	12	0.00042	1.03	0.3480	NS
Group*Condition*AOI	12	0.12950	2.74	0.0496	S

Individual analysis of variance was performed to determine influence of driver experience and driving condition on total percentage fixation. Statistical analyses show that drivers belonging to group 5 spent more time looking at the front and/or center of the visual screen ($F_{(3, 26)} = 3.53$ $p<0.05$) than on the dashboard area while the least experienced drivers (Group 1) spent more time looking down at the first area of interest or the dashboard area or ($F_{(3, 26)} = 4.26$, $p<0.5$) than the front and center view during the simple driving task. Similar results were observed with the case of driving under the complex driving condition in terms of the frequency of fixations on the dashboard and front and center area. The total percentage fixation represents the total number of fixation during the duration of the driving task. The graphs in Figures 4.5 and 4.6 shows the frequency by which objects or the areas of interest were recognized and looked upon by the participants without consideration to the time at which each fixation occurred. That is, these fixations are total fixation on the areas identified.

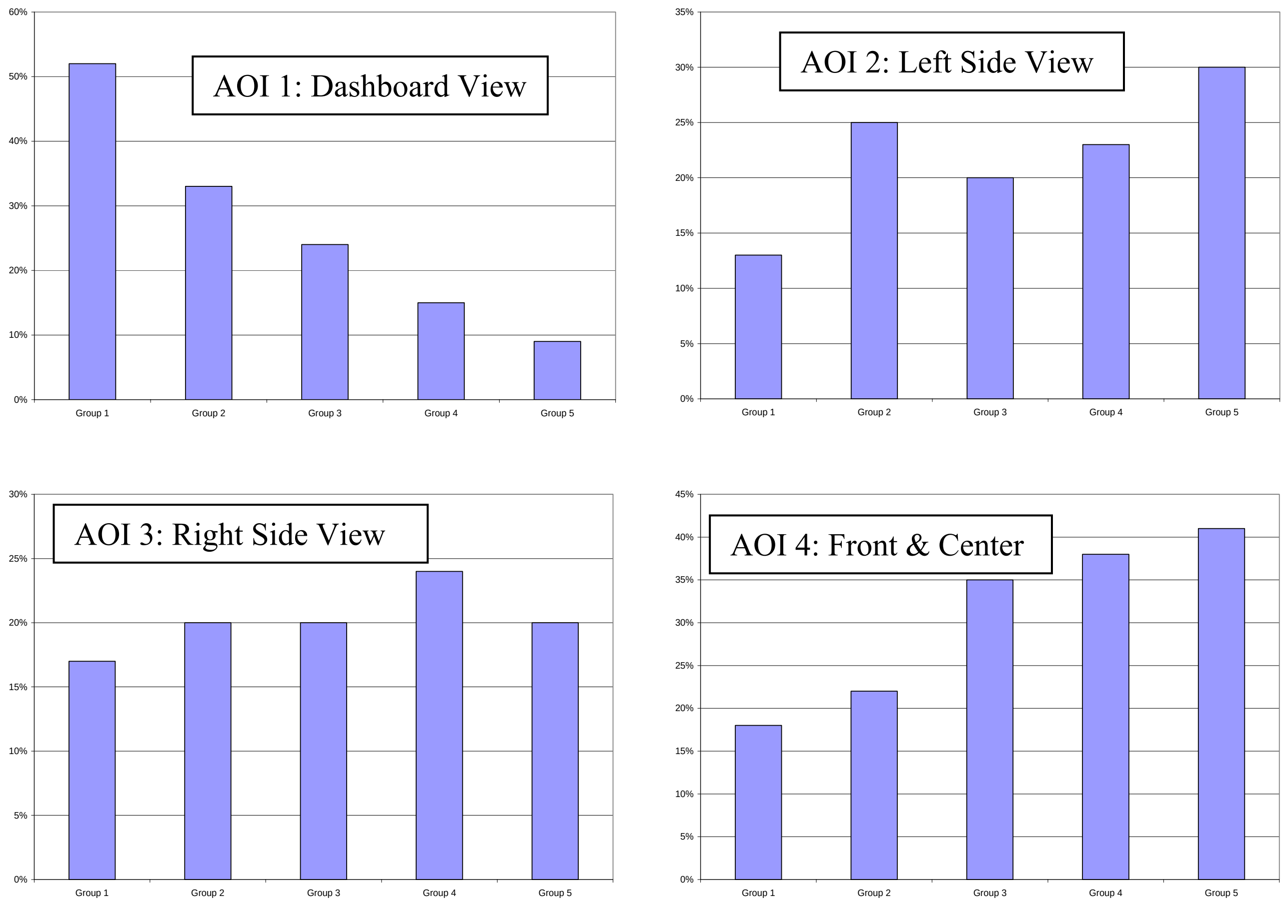


Figure 4.5. Comparison of percentage total fixation at different area-of-interests (simple driving condition).

When driving under the simple driving condition, the more experienced driver fixated more on the front and center view (42%) while fewer fixations was recorded on the dashboard area (18%). There were also a high number of fixations on the left side view (30%). This view contains the road signs and symbols that are of importance to performing the driving task successfully. As such, this view should have more fixation occurrences that should be very similar to the front and center view. These results were in contrast to the results obtained for drivers who are infrequent vehicle users which show more fixations on the dashboard area than on the front and center. There were fewer fixations on the left side view, which contained the important road signs and symbols as shown in the graph.

Figure 4.6. Comparison of percentage total fixation at different area-of-interests (complex driving condition).

A similar observation can be seen for the fixation frequency under the complex driving condition. Although the fixation frequencies recorded for this driving condition were lower than the frequencies of fixation recorded for the simple driving condition, a similar trend was observed: higher number of fixations on AOI 1 for group 1 and higher number of fixations on AOI 4 for group 5. The lower frequency is due to the gaps the gaps in fixation. These gaps accounts for events of no fixation due to loss of eye tracking by the system and those fixations that are beyond the perimeter of the visual screen.

4.3.3. Comparison of Saccadic Path of Drivers

The third parameter used to evaluate driver's behavior is the saccadic frequency. Saccades are quick succession of ballistic eye movement that provides the mechanism for fixations. Comparisons were made on the mean number of saccades for the five-minute driving duration. Saccades were recorded using the pictorial image as shown in Figure 4.1. For each time segment, the number of saccadic jumps was counted. The results for both driving conditions are summarized in Table 4.15. A multivariate analysis of variance with driving condition and experience as independent variables was performed. The results are shown in Table 4.16.

Table 4.15. Saccadic frequency of individual groups during the two driving conditions.

Driving Condition	Group Number				
	Group1	Group 2	Group 3	Group 4	Group 5
Simple	1,054	721	948	987	1,149
Complex	1,267	935	875	1,058	1,346

Table 4.16. Summary of multiple analysis of variance for saccadic frequency as dependent variable at $\alpha = 0.05$ (S – significant; NS – not significant).

Source	DF	SS	F	Pr > F	Effect
Group (Experience)	4	46.17055	6.09	0.0420	S
Condition	1	52.31332	10.39	0.0001	S
Group*Condition	4	101.66667	0.80	0.6063	NS

The values obtained for the saccadic frequency are plotted in Figure 4.7. As can be observed from the graph, generally higher saccades were observed during driving under the complex condition than under simple driving condition ($F_{(1,3)} = 10.12$, $p<0.05$). The increase in the number of objects in the visual scene corresponds to the increase in saccade for the case of complex driving.

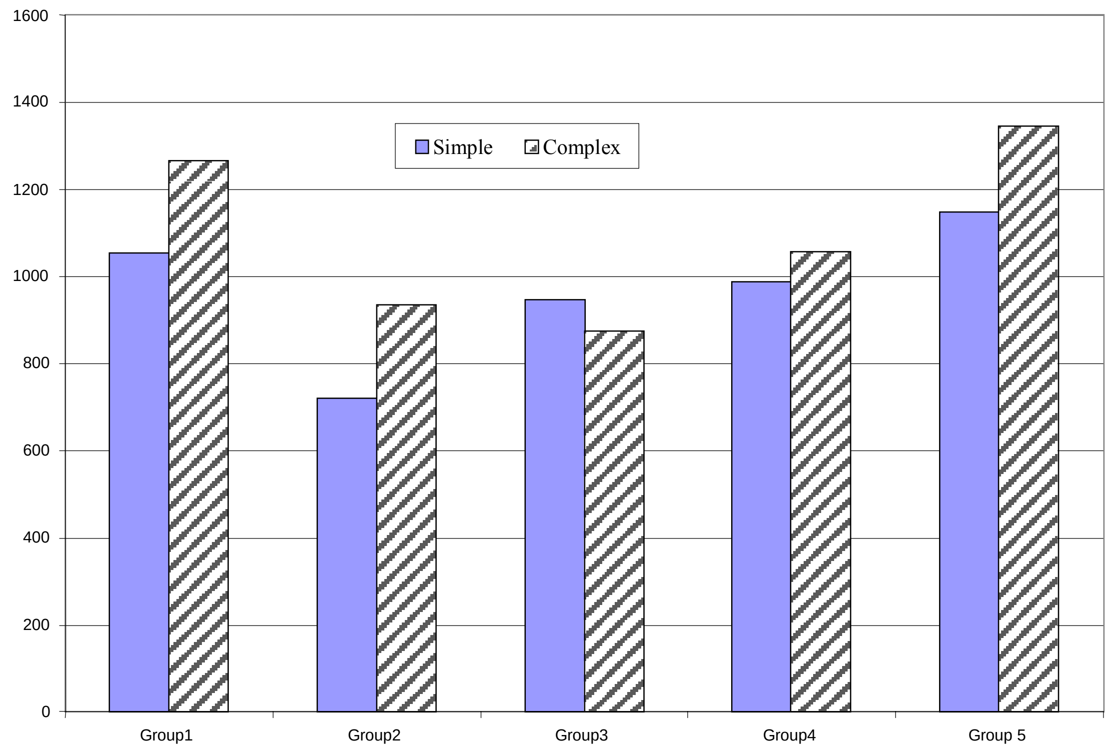


Figure 4.7. Saccadic frequency of the five groups for the two driving conditions.

4.3.4. Driver's Verbal Report and Actual Eye Fixation Match

In order to describe object recognition, the participants were asked to state verbally the objects that they were looking at while driving. The verbal reports were used to match the fixation locations that correspond to the verbal responses from the participants. The audio from the video recording was cross-checked with the video of the entire driving scene. A match was recorded when the verbal report corresponded to the fixation location. The plus-minus one (± 1) second rule was adopted when indicating a match between verbal reports and fixation (Hayashi, et al., 2005). Percentage matches were collected from the audio and video recordings of the participants while performing the driving tasks. These are the numbers of matched reports divided by the total number of reports multiplied by 100. All groups of drivers indicated match rates between 62% to 90%. The percent matches of verbal reports are shown in Table 4.17. The results show an increasing trend of matches of verbal reports and fixation location as driver's level of experience increases. The trend though was slightly offset by the mean percent match of group 3. Over all, participants in groups 4 and 5 both reported match rates of 85% and 90.5% while 2 and 3 have 77.8% and 71.4% respectively, The lowest percent match was recorded from participants in Group 1 with a 62.5% match between verbal report and actual eye fixation location as recorded by the eye tracking device. Statistical comparison of the means of the percent match of the five groups indicate that the means are significantly different ($F_{(4,69)} = 2.96$, $p<0.05$). The values were plotted in a bar graph for comparison.

Table 4.17. Match rates of actual eye fixation and verbal reports.

Group	Total Number of reports (average)	Number of matched reports (average)	Match rates (%)
1	16	10	62.5
2	18	14	77.8
3	14	10	71.4
4	20	17	85.0
5	21	19	90.5

As shown in Figure 4.8, a higher verbal report match was recorded for the most experienced driver. In contrast, a lower recorded verbal and eye fixation matches of objects and location were recorded for the least experienced driver. This indicates that as experience level increases, verbal report increases correspondingly. This also shows that higher match rates are indicative of accurate measurement of fixation location. To be able to match the objects with location of fixations also reveals an interesting degree of object recognition in the visual field.

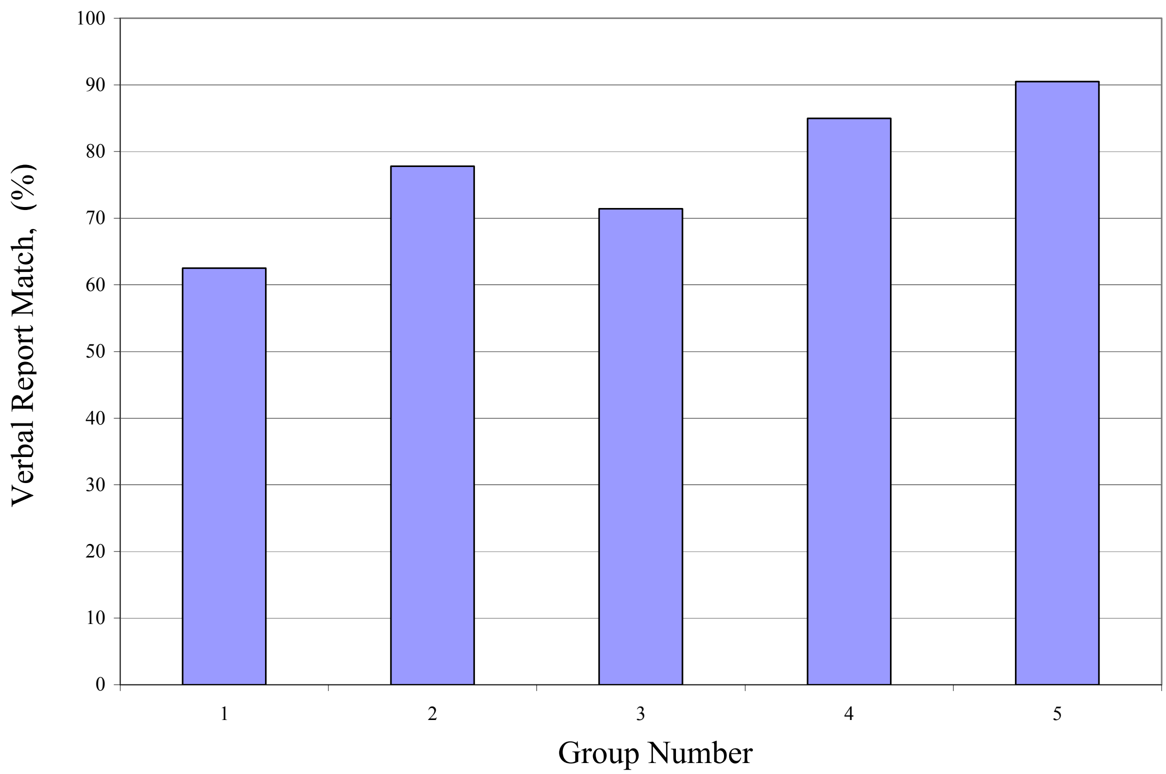


Figure 4.8. Percent match of verbal report and eye fixation of the five groups for two driving conditions.

4.4. Discussions

Studies have suggested that less experienced drivers have different search strategies compared to the more experienced drivers, and that this may contribute to their increased risk of vehicular accidents (Crundall, et al., 1999). This research studied visual behavior of drivers when given a visual stimulus presented in a dynamic scene using two simulated driving conditions. Eye movements were measured using fixation patterns, frequencies, and saccades. As the eye tracking device rely heavily on corneal reflex detection, it may not follow that fixation location is the same as visual recognition of object. As such, the parameters were coupled with the verbal report of fixation of drivers for a more precise analysis of eye movement. These parameters are discussed below describing the visual behaviors of drivers of different level of expertise and at different driving conditions.

4.4.1. Task Complexity, Driving Frequency, and Visual Response

The predetermined monitoring tasks provided a logical sequence of events that drivers must follow in order to perform the task successfully. As shown by the results of the comparison of fixation sequences for the different group's frequency of driving affects the way each group's visual behavior occurs. As the level of driving frequency increases, the ability to operate a vehicle and scan the visual scene also changes. The more frequent users of vehicle (group 5) tend to have a more stable fixation behavior. This was shown by the results of the fixation patterns, frequency and saccades wherein higher fixation frequencies with less saccade were recorded as driving frequency level increases. This observation points toward the ability of the driver to have a better control of the vehicle that is appropriate to the driving conditions.

The complexity of the driving scenes also affects the visual behaviors as indicated by the results. Higher fixations were obtained from simple driving as compared to that of complex driving conditions. The increase in fixation gaps was observed on complex driving mode in contrast to a more continuous fixation patterns for the simple driving mode. The results were in agreement with several studies on visual behaviors using other presentation of visual stimulus (Sodhi, et al., 2002; Strayer and Drews, 2003; Hayashi, et al., 2005). This situation occurs as the visual scene increases in number of objects requiring drivers to process more information. In a complex cycle of tasks inherent while driving, the driver also loses some ability to monitor situations that might be occurring around the periphery but not directly in front of it (Sodhi, et al., 2002). Contrary to operations of other transportation of vehicles such as piloting an airplane (Hayashi, 2003), road based transportation vehicles such as cars require an active eye movement. This is necessary in order to perceive the objects that successively appear on the visual screen. In turn the information is processed one after another in a continuous phase that requires large cognitive demands to human information processing

Tasks that are demanding such as driving influence visual behavior in a variety of ways. For example, the lack of eye movement attributed to visual tunneling under different test conditions has been studied to induce interference in visual search (Williams, 1988). This may reveal further differences between participants with varying driving experience. As shown by the data, groups that used their vehicle less frequently performed differently in terms of visual fixation than those of their more frequent vehicle user counterpart. A comparative analysis of within groups in the two driving conditions also revealed interesting results. Participants from different groupings show a remarkable homogeneity within the particular groups to which they belong. This further provides credence to the assignment of each participant to their respective groups.

4.4.2 Effects of Frequency of Driving on Visual Fixation and Object Recognition

The increase in fixation frequency indicates an increase in object recognition. As can be seen from Figures 4.5 and 4.6, the more frequent users of vehicle have higher fixation frequency than the less experienced driver. This shows that more objects were viewed successfully as the visual scene changes. However, it must be noted that there was a difference between fixation frequency and actual recognition of objects by drivers. It is not uncommon that observers were looking at certain objects without actually recognizing the same objects. As eye movements and perceptual recognition varies, the results of the verbal match were used to validate fixation frequency and object recognition.

4.4.2.1. Verbal Report and Eye Fixation Match Rates

It is well observed that the ability to perceive a visual scene is affected by perceptual and cognitive demands of the driver's search task (McCarley, 2004). In this experiment, the verbal reporting adds to the cognitive load that affects the strategy of searching the environment for visual objects and the processing which occurs within the span of a single fixation. Indeed, the addition of the verbalization of thought or "think aloud" task placed an additional workload to the participants. This was clearly expressed in the post experiment subjective evaluation wherein participants indicated confusion operating the driving simulator control interfaces, the "curiosity and inconvenience" of wearing a head mounted eye tracking device, and the objective in mind of completing the driving tasks.

The match rates indicated the strategies being used by the drivers in each group when scanning their environment. It should be noted that the high percentage of match between verbal report and visual fixation of the fifth group is due to their experience level. Skilled drivers can maintain control of the vehicle by using mostly peripheral vision to monitor the left and right areas of interest. As the data indicate, the percentage of match is lower on the dashboard than the center areas of the visual scene for all groups. This is in agreement with the study using an eye tracking on a flight simulator for pilots of different levels of expertise (Bellenkes, et al., 1997 as cited in Hayashi, et al., 2005). In this study they have found out that pilots made more fixations on the flight variables that were not being maneuvered than the less experienced pilots indicating a good sign of attentional flexibility.

This observation also occurred in the driving experiment conducted. As we can see from the match rates data, the more experienced drivers were seen as having slightly lower fixations on AOI 1 and AOI 3. These areas are where most likely peripheral visions occurred. The outer boundaries of these two areas constitute the tangential environment where objects related to driving still exist, but is in a lesser gravity that directly affects the actions required from the driver. These objects may include vehicle speed and presence of oncoming vehicle.

Attentional capture indicated by fixation results modulated perceptual sensitivity as indicated by the verbal matches. In the driving tasks, the goal to select and fixate on objects was directed by the need of the current tasks. Whether driver fixated on dashboard speed control sign (AOI 1: status tracking group) or left or right (AOI 2 and 3: lane alignment group) back and forth for a given frequency and duration, as long as these are the same group with respect to the visual scene, the recognitions and intentions are the same. Though a reduced fixation output may be observed for multiple presence of object in a driving scene as in the case of an approach to intersection scenario, this does not diminishes the ability of the driver to locate and recognize important objects appropriate for the current situation. The perceptual sensitivity and attentional capture modulation as studied by Theeuwes, et al. (2004) holds true. While the match rates show the differences in the drivers scanning patterns, it also provided proof verifying that objects were recognized and corresponding actions taken during the driving task.

4.4.2.2 Effect of Stimulus Density on Driver's Visual Behavior

The experiment conducted provided data on the effect of visual stimulus that constantly changed in quick succession as the visual scenes changed. Visual behaviors as shown from the fixation patterns and frequency vary with the increase in complexity of the condition. Therefore, the increase in the number of objects present was a major factor.

In comparing for the two driving conditions, a significant reduction in total fixation for the complex driving, as compared to the simple driving conditions, was observed. Also, the results show that fixation duration decreased when driving condition increased in complexity. The increase in the density of objects reveals an interesting downward trend in percentage of total fixation. Different scene provides different objects that vary in sizes, shapes and colors as well as intervals. In a stimulus driven visual scene, attentional capture is modulated by the density of objects and their characteristics (color, distance, size). As discussed by Turrato, et al. (2004), when stimulus characteristics such as distance, color, and size were controlled, the automatic deployment of visual attention is affected by the static discontinuities of the objects.

In a similar fashion, as drivers move on with the operation of the vehicle and as the objects on the road changes in appearance and locations, a discontinuous perceptual modulation of the objects occurs. In this scenario the demand for the driver to quickly fixate and perceive the objects are compromised by the discontinuity occurring as the objects' quickly recedes from the view. The effect is magnified as other objects compete for the limited visual deployment duration for different objects of varying significance to the task of driving. The frequency of saccadic movement increases as drivers cope with the limited time to fixate on objects. It has been experimentally demonstrated that in object detection the accuracy of detecting a target object in a briefly presented scene has been taken as a measure of object identification performance. For example, Biederman, et al. (1983) sought to assess the influence of coherent scene context on object identification by measuring detection performance for target objects presented in normal versus jumbled scenes. In this study, drivers were observed to have brief fixations on several objects that may not indicate recognition. These results were coupled with matched verbal reports and shows that changes do occur with recognition as complexity changes, but not with the change in driver's experience.

In terms of the relevancy of the objects to the tasks, this experiment where gaze is monitored in a simulated driving environment demonstrated that visibility of task relevant information depends critically on active search initiated by the observer according to an internally generated schedule. This is dependent upon learnt regularities in the environment (Hayhoe, et al., 2002). Results of fixation monitoring during simulated driving conditions indicate that task relevant objects where frequently fixated as drivers collect information for performing correct actions. Therefore, road side clutters are objects that compete for the limited visual capabilities of the operators. This is similar to many road vehicle operators such as train engineers as studied by Hamilton, et al. (2005). Considering the demographic characteristics of people who drive, Hamilton shows that roadway engineers are compelled to consider reducing the number of roadside clutters that contributes to competition of allocation of visual fixations from irrelevant signs and those that are central to the safety of the driver.

With similar results, this research shows that the fixations of pertinent signs were more likely when those signs are heavily modulated by the task and by the location of the sign. Looking at the second segment, which is the elapsed time from 150 to 180 seconds where the driver has to pass a school zone, interesting changes have occurred with fixation frequency and patterns. There was a high density of fixation duration and transition to the school zone sign as well as the regulatory sign to reduce speed to 20 mph as compared to other objects in the visual field (e.g. other vehicles and fixed structures such as building). Fewer fixations on road fixtures that are central to the driving scenario indicate a higher probability of making mistakes on the road.

Failure in comprehension can be seen to be a result in failure to fixate on vital road fixtures whether the driver is using peripheral or serial visual search pattern. The risk in driving also increases as the subject's pattern of fixation deviates significantly to critical fixation sequences for a given driving circumstances. Every road conditions speak of different messages from the language conveyed by the signs and symbols. It can be inferred, using the patterns of fixation and its deviation, that there is a failure in communication of these messages critical to the decision making process that drivers must performed. That the state of the driver is not in synchronicity with the language of the road has been experimentally demonstrated which suggested that the pattern of eye fixations reflect to some degree, the cognitive state of the observer (Liu, 1998).

4.4.2.3. Driver's Saccadic Eye Movement

As stated previously, saccades are quick eye movement that brings an area of interest to focus. They are preliminary to fixation and are considered to be events of no fixation. The purpose of saccades is to move the eyes as quickly as possible, so that the point of interest will be centered on the fovea. They can be made not only towards visual targets, but also towards auditory or tactile stimuli such as car interface controls to operate as wiper blades, lights, turn signal levers, thermostat knobs, radio button operations, and other inherent vehicular interfaces.

For this study, all vehicle controls were simulated except for turn signals and mirror controls. The purpose of the simulation is to approximate in as much as possible the actual driving condition so that eye movement behavior can be studied. The results of eye movement using the saccadic frequency to describe visual behavior of drivers show interesting differences in rapid eye shift from one fixation to another. The more frequent users of vehicle and therefore considered in this research as the more experienced drivers show more saccadic frequency than the less experienced driver. Although the results vary little for those groups in between, the general trend is that of increasing saccadic numbers. This can also be observed from the results of driving with increasing complexity.

The increasing trend can be attributed to the driver's tendency to lessen the duration of fixation for each area of interest as the result. As more objects appear on screen, the need to focus on all objects increases as changes in the visual scene occur in rapid succession. It was also observed, similar to the results of other studies, that peripheral vision is mostly relied heavily as density of visual stimulus increases. In studies on peripheral vision, Crundall, et al. (1999) suggested that as the demand and onset eccentricity increases, the participant's ability to detect the peripheral targets decrease dramatically. The results of verbal matches suggest similar findings wherein object recognition decreases as the complexity of driving increases.

4.4.3. Analysis Based on Two Group Combinations

The Tukey-Kramer results indicated in Table 4.4, show that the more appropriate group comparison is between a combination of groups 1, 2 and 3, and a combination of groups 4 and 5. The former is assigned as the infrequent drivers while the latter is assigned as the frequent drivers. An analysis of the total percentage fixation, saccadic frequency and match rates were done and the results are shown below.

4.4.3.1. Total Percentage Analysis

The combined results of total percentage fixation for groups 1, 2 and 3 (infrequent) were compared with the combined results of groups 4 and 5 (frequent). The results for both driving conditions are shown in Figures 4.9 and 4.10.

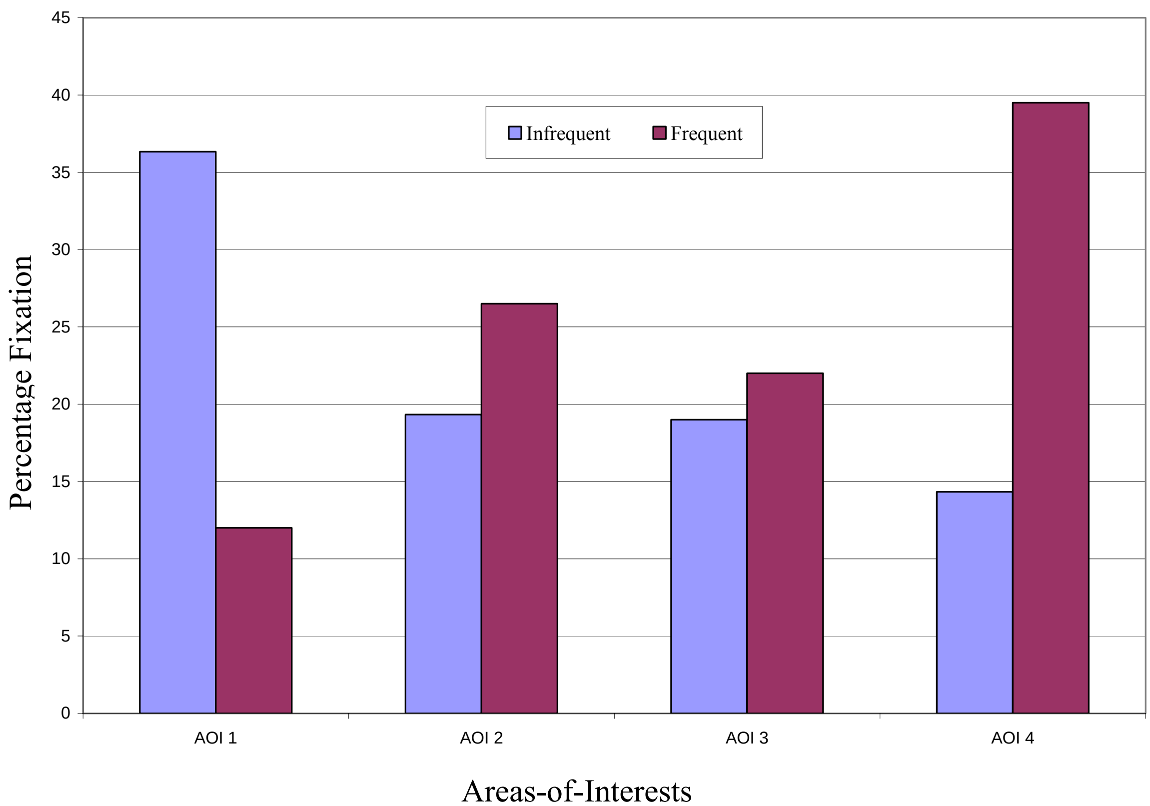


Figure 4.9. Comparison of percentage total fixation at different areas-of-interests for infrequent and frequent vehicle users (simple driving condition).

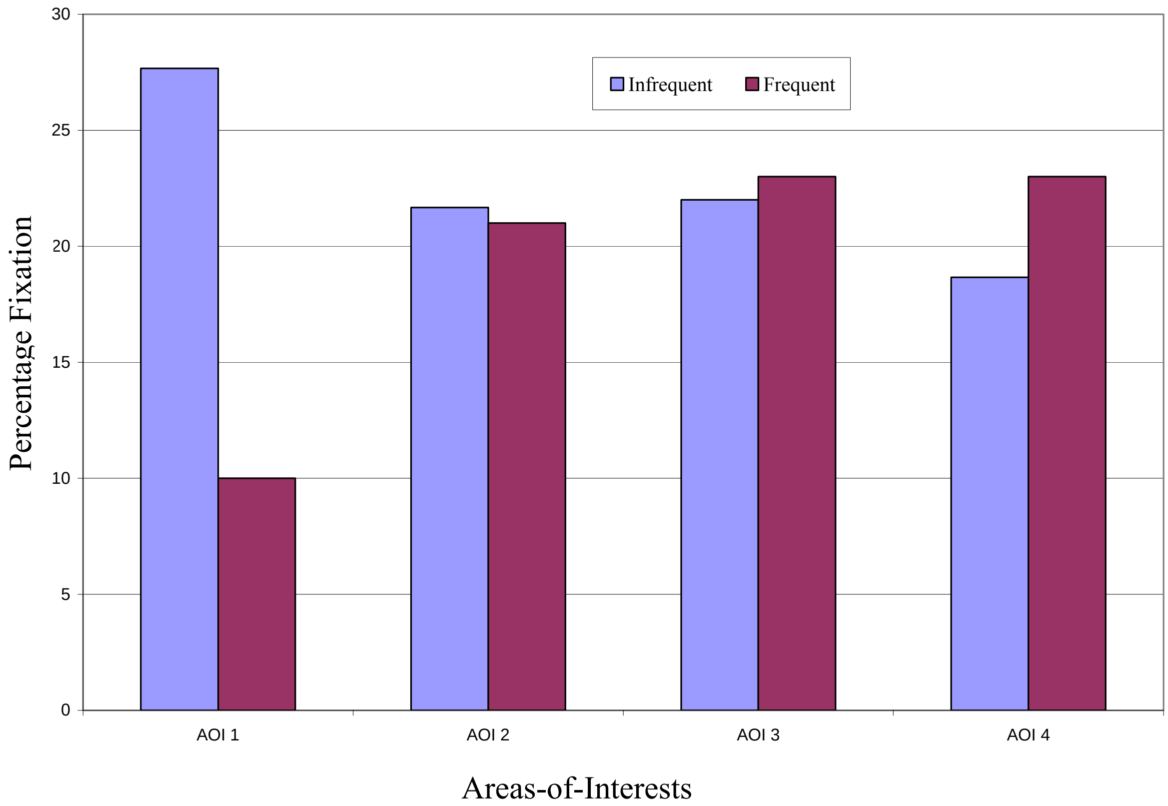


Figure 4.10. Comparison of percentage total fixation at different areas-of-interests for infrequent and frequent vehicle users (complex driving condition).

The comparisons of percentage total fixation at different areas-of-interests for infrequent and frequent vehicle users indicate the similar results for the two driving conditions. For both the simple and complex driving conditions, the infrequent vehicle users fixate more on the dashboard area than on any other areas of interest. In contrast, drivers who are frequent vehicle users fixate more on the front and center than any other area. The fixation on the front and center indicate a better control of the vehicle as the drivers belonging to this group have a wider area of visual focus. Fixating more on the dashboard, as shown by drives who are infrequent vehicle users, limits their ability to assess the visual scene and the surrounding driving environment. This exposes the infrequent drivers to a higher level of risk than the frequent vehicle users.

4.4.3.2. Saccadic Frequency Analysis

The saccadic frequencies of the infrequent and frequent drivers were also compared. A combination of the saccadic frequencies of groups 1, 2 and 3 was compared with a combination of the saccadic frequencies of groups 4 and 5. The results are shown in the figure below.

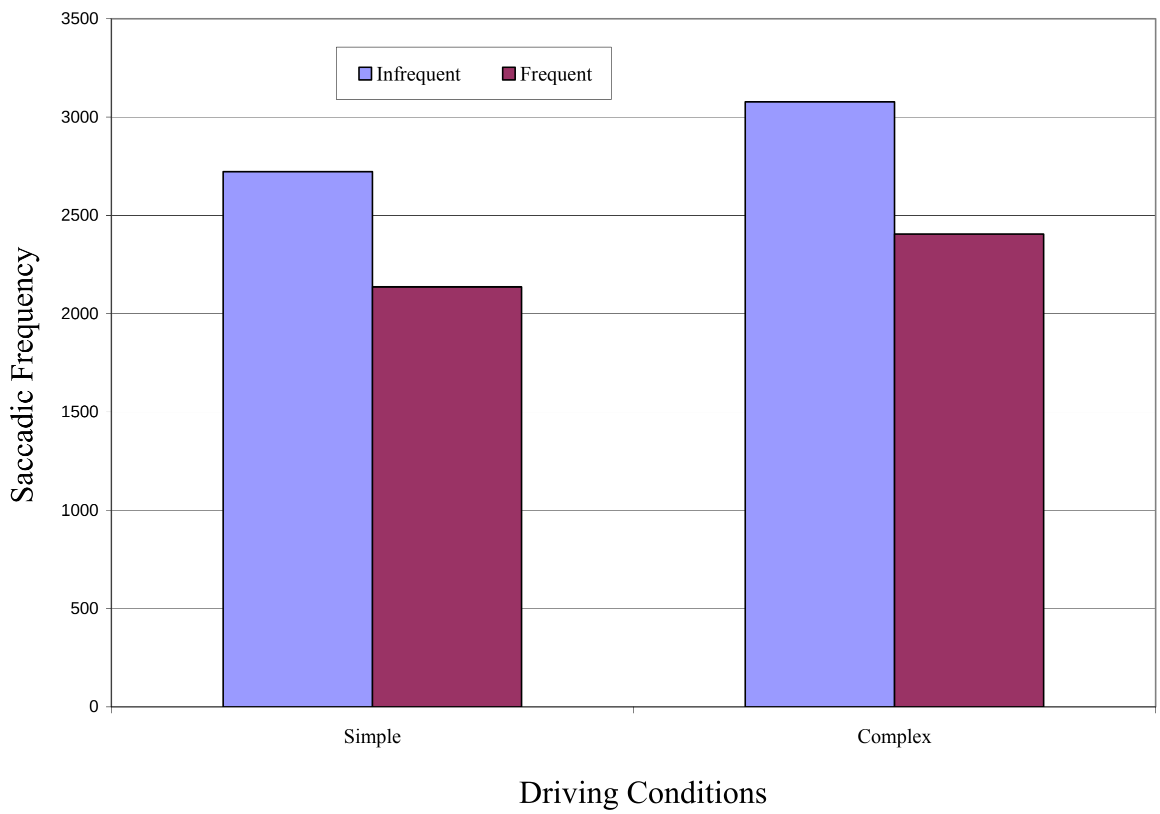


Figure 4.11 Saccadic frequencies of the infrequent and frequent drivers for the two driving conditions.

The results obtained by using the frequent and infrequent vehicle users as group combinations, show an increase of 12.8% in saccadic frequency when driving condition becomes complex. When frequency of vehicle use increases, there was a 27% reduction in saccadic frequency. The higher saccades correspond to the driver's ability to allocate the visual fixation as objects in the visual scene increases.

4.4.3.3. Match Rates Analysis

The match rates between the frequent and infrequent group of drivers were compared. The results are shown in Figure 4.12. A higher match between the verbal reports and the eye fixation of the frequent vehicle users were observed. The match rate for this group was 87.75%. In contrast, the infrequent vehicle users showed a lower match rates. The value obtained was 70.56% match. As can be seen from the figure below, the 17.19% difference indicates that drivers who are frequent vehicle users were able to fixate better on the visual scene than drivers who are infrequent vehicle users. The increasing trend is also similar to the previous percent matches shown in Figure 4.8 wherein the match rates increases as frequency of driving increases for all groups.

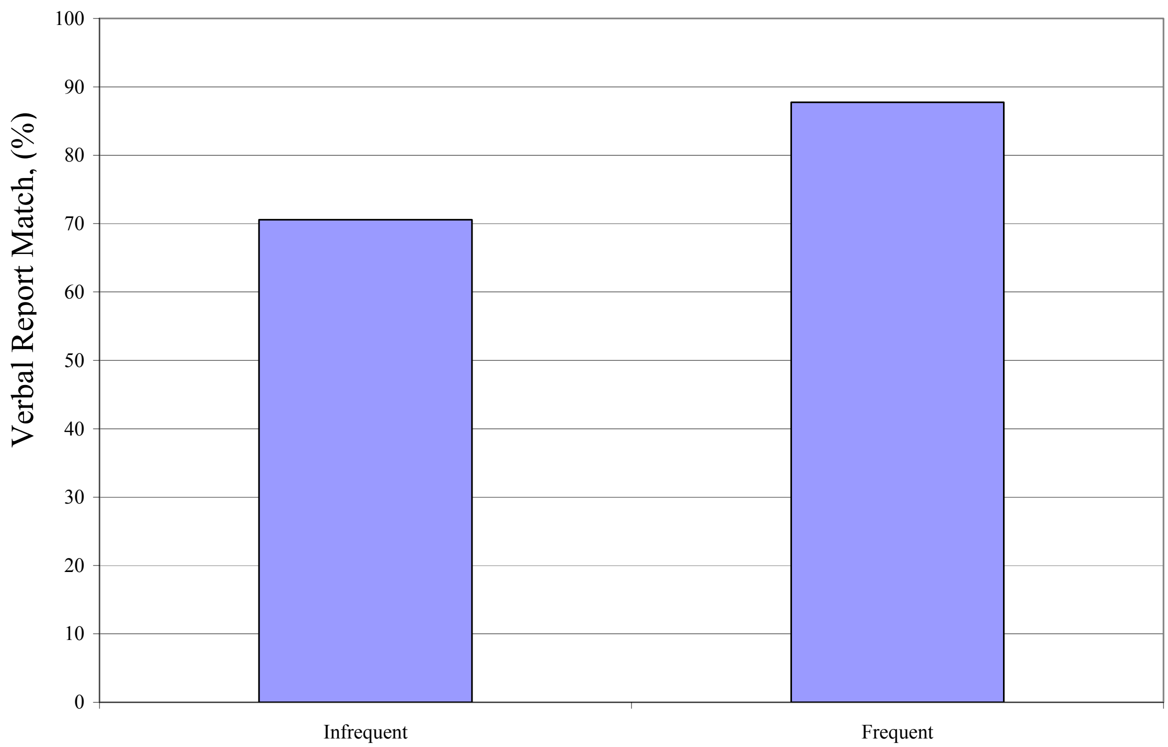


Figure 4.12 Percent match of verbal report and eye fixation of the two groups for two driving conditions.

4.4.3. Complexity of Driving Scene and Allocation of Visual Ability

Using the results of fixation pattern, frequency, and saccadic path, the effect of the number or density of objects in the visual scene indicates that as the density of objects increases, the time spent on each AOI decreases. It can be seen that there are differences in the amount of time spent on the four AOIs. The video recording indicated that the complex driving condition has 34% more objects that are embedded in the visual scene than the basic driving scenario. Figure 4.4 (complex driving condition) shows more fixation gaps in sequences than Figure 4.3 (simple driving condition). A comparison of the mean number of fixations was made. It can be seen in the figure that the mean number of fixations for all participants is considerably higher in the simple mode than in complex mode. Conversely, the saccadic or high ballistic eye movements that facilitate exploration of the visual field are higher in the complex than in simple driving mode ($F_{(1,3)} = 10.12$, $p<0.05$). The implications of the differences is that when engaged in a tasks that requires allocation of visual ability to fixate on objects, drivers do not scan the road similarly for different conditions. The gaps in the second graph can be seen as an attempt recognize as much objects as can be, given the rapidly changing visual scene. The dispersion of fixations was evident in both the patterns of eye movement. The dispersion can be seen as a characteristic of limited deployment of visual fixation of the participants. As more objects are presented in quick succession, the times spent on different objects on the areas of interest are diminished. This shows that object clutter contributes to the allocation of visual glances to the objects. In the complex driving scenario, more objects are required to be fixated in order to perform the driving tasks successfully. Compared to the concentrated visual fixation in the simple driving scenario, the concentration signifies more visual allocation resources as more time is allotted for objects in the visual scene. This situation is similar to the results of studies by Downings (2004) where in it was concluded that eye movement is fractioned to allow maintenance of critical items.

4.5. Conclusions

An experiment to determine the effect of driver's individual differences based on frequency of use of vehicle and driving condition on the visual behavior of drivers was conducted. This experiment supported the conclusion that the differences in visual behaviors brought about by the two factors affect the object recognition. This meant that even at different driving experience and complexity of task in driving, participant's ability to recognize objects in the visual field changes. In contrast to other studies in visual behavior where objects were shown in static mode, this study presented the object in a dynamic condition. This meant that objects appeared in rapid succession just as expected in a normal driving scenario. This provided an interesting observation in studying visual behavior. As the results have shown, fixation patterns and numbers changed as the condition become more complex. The more objects presented, the less fixation duration were observed resulting to a higher saccadic movement. The experiment also showed the reliability of using eye tracking system to measure eye movement. This was illustrated in the verbal reports which showed that fixation corresponds to participant's visual recognition of the object. A high match on verbal reports and fixation, especially for the more experienced participants, was recorded. The object recognition ability of drivers was not affected by differences in visual behavior. This was shown during the evaluation of the eye movement in terms of fixation location and frequency of fixation at specific points in the visual screen. The results showed that despite the differences in scanning the objects, the drivers of whatever level of frequency were able to identify the objects in the road necessary for driving albeit in varying degree of patterns of visual fixation. The study also showed that the differences in fixation or scanning strategies were affected by the complexity of the driving condition. As the number of objects in the visual scene increased, the visual strategies also changed. The changes were noted when drivers distribute and allocate their visual capacity. This was where the largest margin of difference exists.

CHAPTER 5

EXPERIMENT 2:
EFFECT OF DISTRACTION ON VISUAL BEHAVIOR AND DRIVING PERFORMANCE

5.1 Introduction

Driving is a complex task characterized by interleaving factors that require the driver to process information continuously. To safely operate a vehicle, the driver's responses to multiple stimuli must be immediate and appropriate. Technology plays a major role in safe driving. The technological advancement in vehicle safety from mechanical systems (e.g. seat belts, airbags, collapsible steering wheels, anti brake system), navigational systems (e.g. global positioning system), to public awareness (e.g. anti-drunk driving campaigns) has been effective in reducing vehicular accidents. It is plausible to imagine that the next generation of technology will further decrease roadway accidents.

One of the most important considerations for these new technologies to work would be their capability to assist drivers in preventing the accidents. Information technology devices used while operating the vehicle, whether or not intrinsic to the vehicle, have been alleged to affect driving performance. In-Vehicle Technology (IVT) such as cellular phones, visual display monitors and the likes, have changed our driving lifestyle. The roadway is full of signs, symbols, and other stimuli which convey information that need to be processed in quick successions. The different stimuli that are presented to the driver must be compared to the intentions of the tasks. Several researches have focused on the dynamic aspect of the environmental factors and its effect on the performance of the task. Studies of the relationship of eye movement and distraction by engaging in secondary tasks such as cellphone usage serve to indicate the existence of certain scanning strategies different from normal driving task.

Historically, secondary task engagement has typically been attributed to driver distraction. In a recent study by NHSTA and Virginia Technology Transportation Institute, drowsiness accounts for 22.1% of the cause of vehicular crashes. While those associated with the use of cellular phone comes in second at 7.14% (Neale, et al. 2005). Inattention is the common ground for all the factors as shown in Table 5.1. Humans have the inherent willingness to engage in associated risk of distracting activities while operating their vehicle. For many, it seems that the act of driving itself is a skill that has become ingrained in their system that they feel they are confident enough to attend to other task no matter how unrelated they are from the primary task of driving. However, such confidence results in many tragic events, resulting to loss of lives and properties. The effects of these factors are discussed in the proceeding sections.

Table 5.1. Contributing factors in driver's behavior (*Source: Neale, et al. 2005*).

Contributing Factors	**Percent Contribution**
Drowsiness	22.16
Dialing hand-held devices	3.58
Talking/Listening to a hand held device	3.56
Reading	2.85
Eating	2.15
Applying make-up	1.41
Reaching for an object	1.23
Reaching for a moving object	1.11
Looking at external object	0.91
Insect in vehicle	0.35

Today's societal driving tendencies and inclinations vary as the advances in information technology pervade and affect many aspects of human behavior, particularly our ability and penchant for multitasking. The effect of technology on information dissemination has not failed to capture the interest of researchers in many field of physical and social science. In driving, the impact on safety is profound as statistics continue to correlate to the number of vehicular crashes that involve the use of cellphone, which is by far the most prevalent technology on board any vehicle. With interfaces that require manual input as in dialing a number, these devices demands visual attention. This attention, already limited by the density of objects in the visual scene demanding allocation, is further strained to the point in which the probability of detrimental consequences increases. Even improvements in these technologies, such as voiced-based interactions, are however not effortless. Therefore, road safety researchers have raised concerns on the potential for distraction (Goodman, et al., 1999).

Several studies were conducted in an attempt to study human behavior and driving. Studies such as the use of cellular phone while driving, provide interesting results in which the content of the conversation is also a factor in safety consideration. For example, as correlated by Redelmeir and Tibshirani (1997), the risk to driving continues even after the conversation ends because afterthoughts related to the conversation persist in the drivers mind. Much of the information on the road needed for safe driving is taken visually. This is the medium by which cognition begins. Thus any changes in driver's visual patterns or behavior could potentially increase the risk of accidents.

The evaluation of human cognition as an input in the development of accident mitigation in the transportation safety requires an understanding of the pre-crash causal and contributing factors. This research seeks to provide a level of understanding between the relationship of driver's visual behavior and driving performance, as well as the factors associated with accidents caused by physical and mental distractions. However, the specific effects of distraction on visual attention and its influence on visual behavior in general have not been fully understood (Duchowski, 2003). Thus, it is important to relate visual behavior to cognitive functions as task complexity increases in operating a vehicle. The intricacies of performing a critical task coupled with secondary tasks have significant impact on driver's visual behavior and on how he/she develop a strategy to attend and perceive the objects in the visual scene.

Thus the hypothesis for this study is:

H_1: Physical and mental distraction associated with the use of in vehicle technologies (IVT-cell phone) affects driver's performance.

In this study, the secondary task that was used as a distraction while driving was the use of cellular phone. The act of dialing a number and simulating a conversation were used as the physical and mental distraction. This study addresses the driver's visual fixation characteristics and the role of inattention and distraction in a simulated driving scenario. Furthermore, it provides a first step approach into incorporating driver's visual behavior in the development of systems that could effectively assist drivers in adverse driving conditions.

5.2. Experimental Tasks

Similar to the first experiment, the driver used a head mounted eye tracking system and a driving simulator with thrustmaster pedal and steering wheel to control the vehicle. The driving condition used in this experiment is the same driving condition used for the complex driving condition in chapter 4. In this condition, the driver assessed the risks and took proper actions to avoid vehicular collisions. Drivers were presented with reckless drivers on the road as well as road conditions requiring him or her to perform defensive maneuvers. However, in this experiment, secondary workloads were added to the driving tasks. The workloads were a combination of mental and physical loads.

In the physical workload, the participants were asked to dial a cellular number. This number connected to a third person located in another adjacent room. The third person was intended to answer his/her cellular phone. The mental workload begins when a series of questions were asked to the participants by the third person (Appendix F). These questions ranged from history, geography, logic, mathematics, and trivia. Each question required a verbal response from the participants. The questions were designed to initiate a simulated conversation. The questions were asked at different time interval while the participants were driving the simulator. The participants used their own personal cellular phone for which they are familiar with its button's location and operation.

At the end of the experiment, a workload rating (NASA TLX) was used where participants evaluated the workload both in terms of driving and distraction. Subjects read the rating scale definitions and the instructions. A copy of the scales is included in Appendix G, for use in briefing subjects. Subjects practiced using the rating scales after performing a few task, to insure that they have developed a standard technique for dealing with the scales. A second post experiment survey questionnaire designed to assess the participants perception of safety was used thereafter (Appendix H).

5.3. Evaluation of the Effect of Secondary Tasks on Visual Behavior

Thirty-eight individuals participated in this experiment on a voluntary basis. In evaluating the effect of eye movement on driving with (mobile phone conversation) and without distraction, this study used data from the iViewX eye tracking machine recorded on scene images. Eye position measurements were recorded for each participant. All of the participants were not able to complete the five-minute driving task. At some point, the driving experiments for all participants were terminated for a variety of reasons such as vehicle crash, excessive traffic violations or not following driving instructions. All participants reported experiencing difficulty in driving. The average length of driving for all participants was 2 minutes and 15 seconds for the driving conditions selected. Given this situation and in order to provide a consistent condition for analyses, only a specific segment of the total driving time that was common to all participants was used for data analyses. This segment corresponds to the time at which the subject was driving on specific section of the road.

Studying the impact of distraction on driving behavior, eye movement was used as objective measures to describe the impact of secondary tasks in this experiment. The results show interesting aspects in which the driving behaviors of the drivers at different expertise level were affected in a variety of ways. One objective and two subjective measures were used in this study. The first is the objective measure of visual behavior analysis using visual time off screen and percentage total analysis while the subjective measures are the NASA TLX workload assessment test and post experiment questionnaire on safety perception.

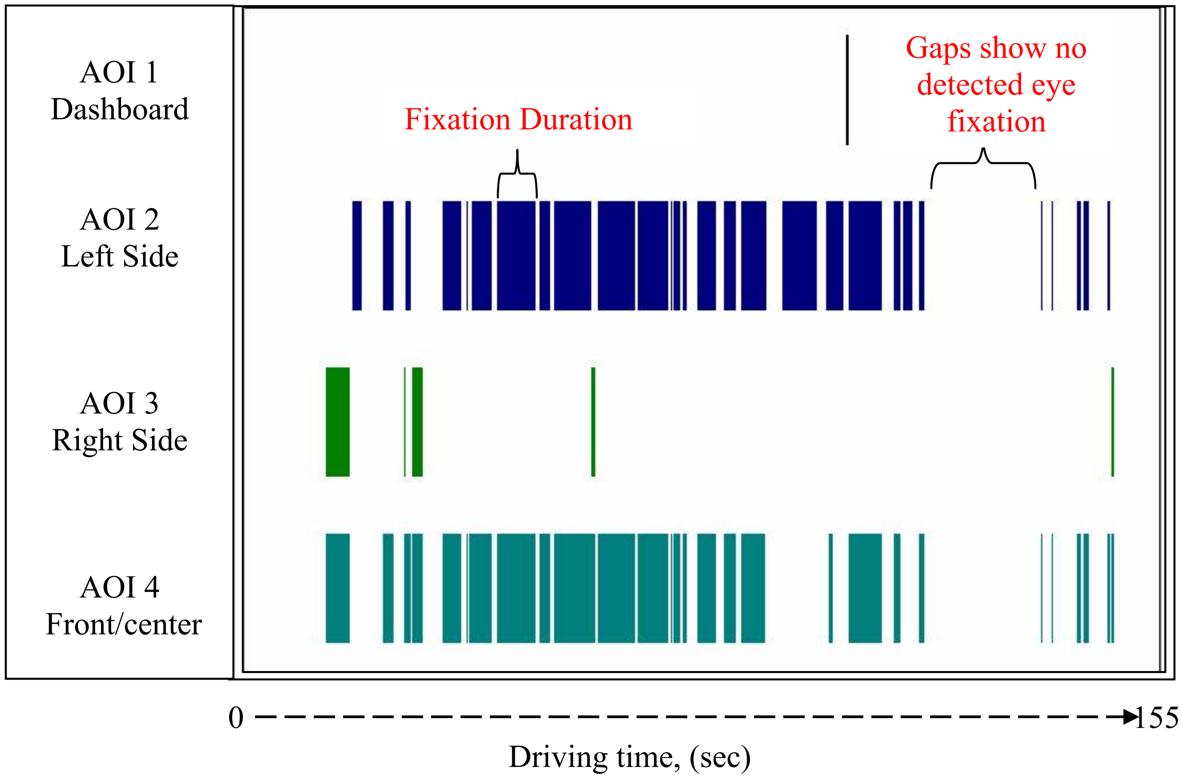
5.3.1. Eye Movement Measurements (with and without Distraction)

The degradation of attention or visual focus is the immediate effect of distraction in almost any situation. In this study, the degree of inattention was quantified using the amount of time that the drivers were not looking at the visual screen. This was measured by determining the amount of time that the driver was not looking at the visual scene.

Primarily, the visual inattention or visual time off screen was attributed to the operation and use of cellular phone. In effect, the distraction can be said to consist of two forms. The first is the physical distraction of dialing and using the cellular phone and the second is the cognitive distraction of conversing with another person.

As mentioned previously, none of the participants were able to complete the five minute driving task while using cellular phone. The average duration was 2 minutes and 15 seconds. Eye movement measurements were therefore based on this driving time and not on the entire duration of the session. The first measure used was the eye fixation sequence and duration. Figure 5.1 shows the order of object fixation for the specific driving elapsed time. The graphs, taken from the result of the order of objects analysis from the eye tracking analysis software, represent fixation order and duration for driving with a distraction (above) and without distraction (bottom). These results show an interesting view on the changes that occur to visual behavior when driving with without distraction as compared to that of driving with distraction brought about by use of cellphone.

As compared to driving without distraction, the graph for driving with distraction shows a concentration of and with wider bars on area-of-interest 2 and 4, the left side and front/center views respectively. On the other hand, when distraction was removed, scattered fixations with shorter durations were observed. Results also show longer gaps (distance between bars) occurred for the case of driving without distraction. Three kinds of information important in analyzing visual behavior can be determined from the graph. These are the location and duration of fixation and the time off screen. Each bar represents fixation at a specific area of interest and driving elapsed time. The width of the



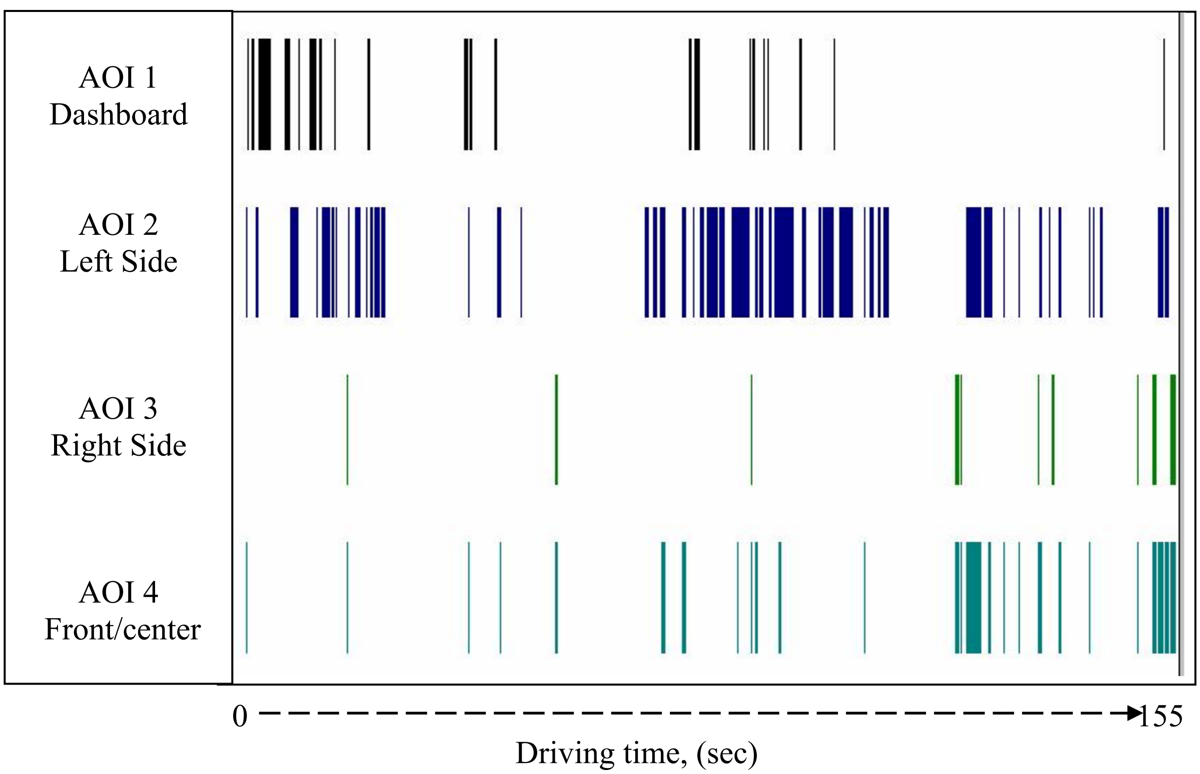


Figure 5.1. Sequence and duration of fixations for drivers who are frequent users of vehicle with distraction (top) and without distraction (bottom).

bars shows the duration of fixation while the gaps between bars represent gaps or events wherein no fixation was detected by the eye tracking machine. The amount of time that no fixation was recorded on the areas was computed for each group and expressed as percentage. That is, the amount of time of no fixation was divided by the specific total amount of time of driving (155 seconds) multiplied by 100 on both driving conditions. The results are shown in Table 5.2 and were plotted in Figure 5.3.

Table 5.2 Percentage of time with no fixation detected (Visual time off-screen).

Group Number	Time of no fixation detected (%)	
	With cellphone	Without cellphone
1	35	48
2	22	32
3	34	36
4	31	34
5	12	24

An analysis of variance between and within groups was carried out. The results indicated differences existing between groups exposed to two different conditions of driving ($F = 6.98$, $p<0.05$). The table shows that there is a general decreasing trend as experience level increases for the case of driving with distraction. Less amount of time was consumed by distraction when drivers are experienced as compared to when drivers were considered less experienced. Interestingly, the eye tracking system recorded more fixations of longer duration when driving with distraction than without distraction. This indicates steady eye fixations on a particular location of the visual screen. This is quite an unexpected result as one might observe that drivers are visually constrained while performing two tasks simultaneously. For task requiring driving alone, the fixations can be seen from the graph as having more fluctuations that are sudden and frequent based on the events that occur while driving. These observations were then used to relate the effect of distraction and driving performance using the six driving errors.

5.3.2. Distraction and Driving Performance

Driving performance was evaluated based on the number of errors committed. These errors were identified initially as potential errors that were commonly committed by drivers. These errors include:

- Lane Crossing (LP) - vehicle excessive swerving from left and right of the assigned lane
- Safe Distance Maintenance (SDM) - requires the driver to maintain an appropriate distance from the vehicle in front to avoid collision
- Speeding (SP) - errors of driver that exceeds mandated speed limit
- Collision (C) - occurs not only when two vehicle collide but also when subject vehicle collides with other objects on the road
- Pedestrian Lane (PL) - error occurs when vehicle do not stop behind pedestrian lane
- Crossing Red Light (CRL) error is for vehicle that passes a red light in intersection.

The number of errors was tabulated during a thorough review of the videos recordings of the driving sessions of all the participants. The feedback from the driving simulator indicating the frequency and type of errors committed were verified for correctness based on the specific tasks. The results are shown in Table 5.3.

Table 5.3. Summary of driving errors committed during driving with and without distraction.

Group No.	Driving Condition	Frequency of errors committed while driving						Total
		Lane Crossing[1]	Safe Distance Maintenance[2]	Speeding[3]	Collision [4]	Pedestrian Lane Crossing[5]	Crossing Red light[6]	
1	With distraction	4	4	3	3	4	2	20
	Without distraction	5	2	4	2	1	3	17
2	With distraction	3	4	4	3	3	2	19
	Without distraction	5	2	1	2	2	1	13
3	With distraction	2	2	4	4	2	2	16
	Without distraction	2	2	4	3	2	1	14
4	With distraction	2	2	2	2	4	1	13
	Without distraction	3	1	1	2	1	1	9
5	With distraction	3	2	2	4	1	1	13
	Without distraction	2	2	2	1	3	1	11

Notes:

[1] Swerving beyond the left and right of the driving lane

[2] Driver must maintain a one distance of car-length per 10 miles of speed

[3] Speed required exceeded

[4] Participants vehicle collided with another vehicle or fixed objects

[5] Vehicle must stop behind pedestrian lane when stopping at pedestrian crossings

[6] Traffic lights violation

A multivariate analysis of variance was performed to determine any over all effects of driving experience (n = 5) and specific errors (n = 6) and their interaction on the number of errors committed. Table 5.4 summarizes the results. The statistical analysis shows that group effect is significant. The same results were also obtained for the specific errors committed. On the other hand, no significant interaction effect of group and errors was observed.

Table 5.4. Summary of multiple analysis of variance for the number of errors committed as dependent variable at $\alpha = 0.05$ (S- significant; NS – not significant).

Source	DF	SS	F	Pr > F	Effect
Group (Experience)	4	1.66153	10.56	0.0001	S
Errors	5	15.8566	15.59	0.0001	S
Group*Errors	20	1.20865	0.06	0.8899	NS

Lane crossing accounted for the most number of errors contributing 21.38%, followed by vehicle speeding at 18.62 % and collision at 17.93 %. In other parameters, such as maintenance of safe distance, mixed results were obtained for the different groups. In vehicle collision, it should be noted that this factor is measured in terms of observable collisions with another vehicle, gutter or ditch, road signs, and other objects that causes the vehicle to stop. Since it was possible to detect all crashes regardless of severity, it is interesting to note that considerably high in this factor is the third group while they are using the cellular telephone.

The results show that the number of errors did not change significantly. The same results can be observed in other specific errors mentioned. Further comparison of the results as displayed graphically in Figure 5.2, which indicates that lane crossing was the primary error, committed while driving and using a cellular phone. Though it is difficult to empirically show the level of risk in relation to the degree of exceeding designated driving lanes while driving It was observed that this becomes inherently dangerous if we consider speeding as the second most committed error in this task. This is the same case for driving without cellular phone wherein lane crossing accounts for the most frequent errors committed. In comparing the group's experience level based on frequency of driving, one can see that a higher number of errors were committed by group 1 while group 5 has the fewest. Over all comparison shows that there was an increase of 26.56 % errors committed. This translates to an increase from 64 total errors committed for driving without distraction to 81 total errors committed for driving with distraction.

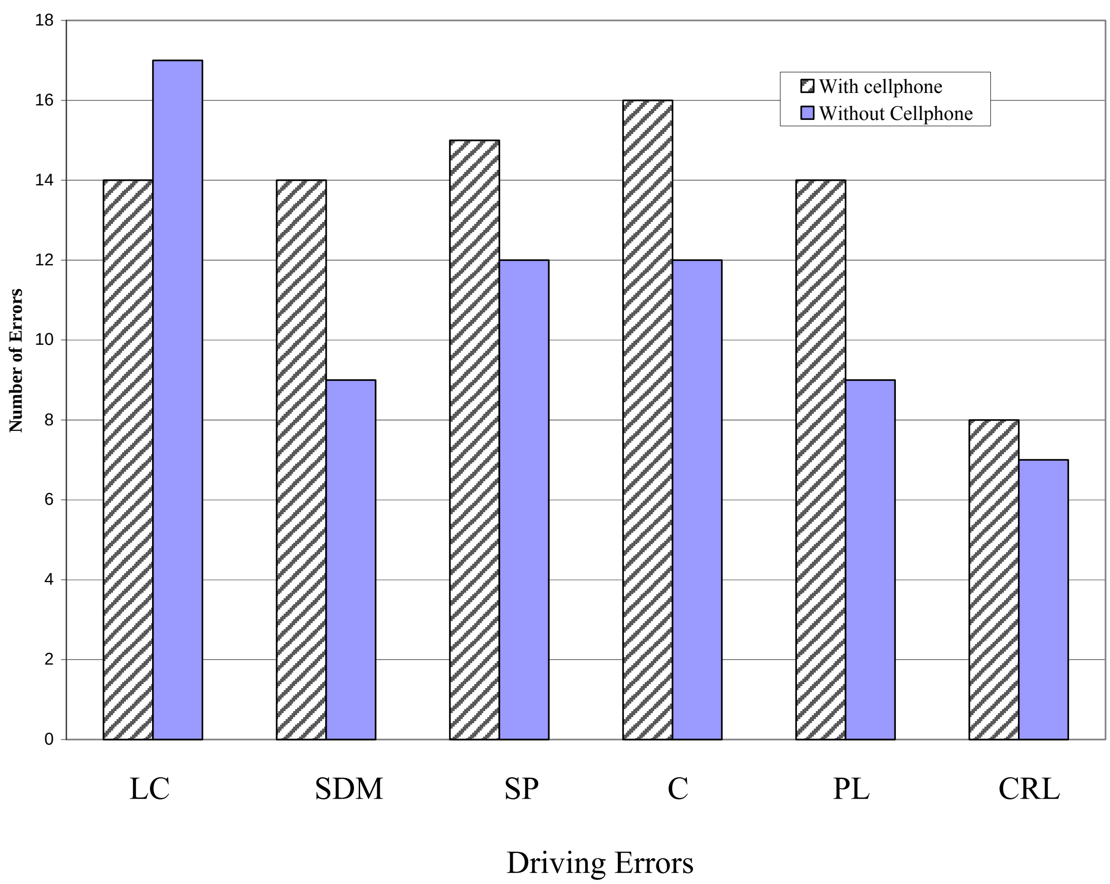


Figure 5.2. Total number of specific errors committed by all groups.

The relationships of no visual fixation on the screen and number of errors committed for both conditions were evaluated. The number of errors was compared to that with the visual time off screen. The values for both parameters were plotted in Figure 5.3. The general trend that the graph shows was that the higher the visual time off screen, the higher the errors. The values recorded where higher for the condition with distraction than driving without distraction. For groups three and five, there were slight increases in the number of errors committed even without distraction. The difference in the number of errors committed between the two driving conditions ranges from a low of 3 for groups 3 and 5 to a high of 7 for group 2. In this study, using the number of errors as a metric for performance, the results show that there was a decrease in driving performance from 18% to 55% due to the inclusion of secondary task.

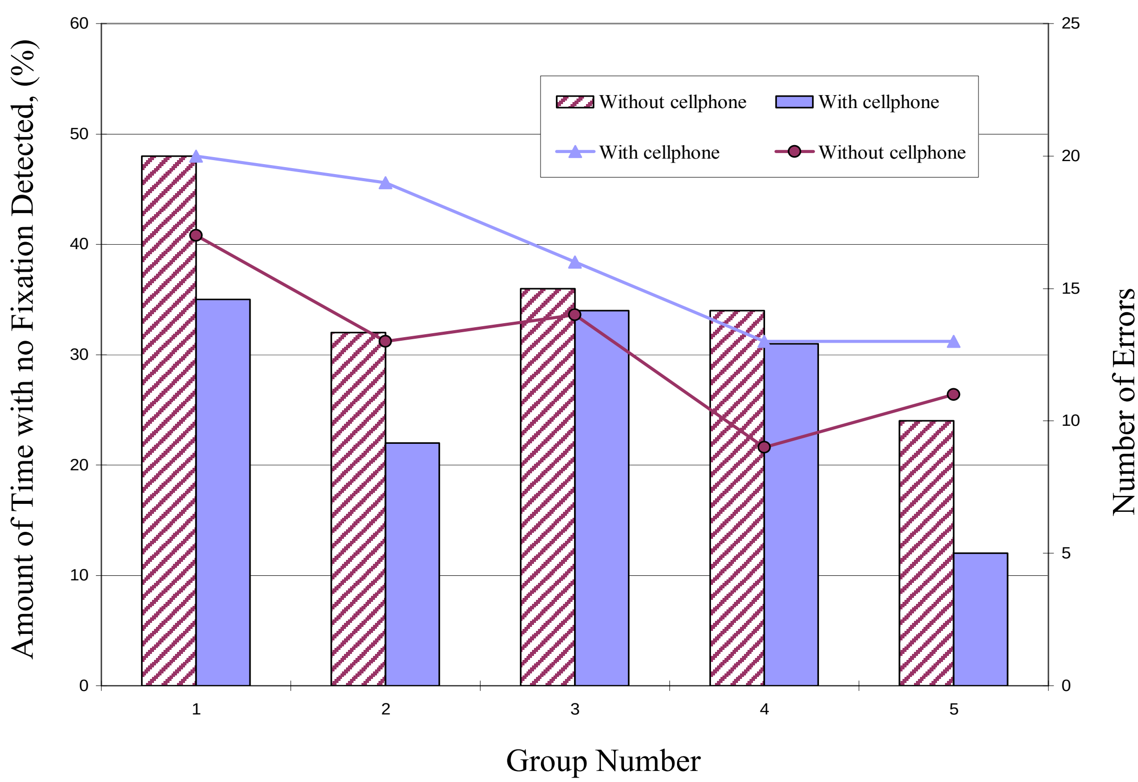


Figure 5.3. Number of errors (lines) and amount of time with no fixation detected for the five groups of drivers.

Percentage of Total Fixation of Drivers

An examination was also made as to whether changes occurred in fixation on the visual stimuli when drivers were performing additional tasks while driving. Using the same areas of interest as defined in Figure 3.6 as shown in chapter 3, the viewing percentages for each area of interest were analyzed. The results for both driving conditions are shown in Table 5.5.

Table 5.5. Percentage fixation at specific areas of interest for two driving conditions.

Group #	Areas of Interests	Viewing percentage	
		With cell phone	No cell phone
1	1	37	52
	2	12	39
	3	0	12
	4	12	16
2	1	1	78
	2	2	32
	3	3	5
	4	5	34
3	1	28	59
	2	47	46
	3	4	7
	4	13	31
4	1	1	16
	2	2	24
	3	3	10
	4	4	12
5	1	42	48
	2	20	15
	3	5	6
	4	28	48

A multivariate analysis of variance was performed to determine any over all effects of driving experience, secondary tasks (distraction), and areas of interest on total percentage fixation. The effects of the interactions of the variables were also analyzed. Table 5.6 shows a summary the statistical analysis. The results of the multivariate analysis of variance were significant for the factors groups, areas of interests and distraction. The interaction of distraction and AOI are also significant. On the other hand, no significant interaction was found for a three way interaction of the factors. An independent analysis of variance was conducted to determine the between groups and between areas of interest effect on total percentage fixation.

Table 5.6. Summary of multiple analysis of variance for the total percentage fixation as dependent variable at $\alpha = 0.05$ (S – Significant; NS – Not significant).

Source	DF	SS	F	Pr > F	Effect
Group (Experience)	4	0.6394	5.18	0.0001	S
Distraction	1	0.3772	4.92	0.0001	S
Group*Distraction	4	0.9688	0.5290	0.8947	NS
Areas of Interest (AOI)	3	0.9564	2.28	0.0018	S
Group*AOI	3	0.8414	0.1546	0.0021	S
Distraction*AOI	12	0.6546	0.4311	0.8499	NS
Group*Condition*AOI	12	0.9351	0.0993	1.0000	NS

The comparisons between groups and between areas of interest using two driving conditions were performed. The results indicate that the percentage of fixation between groups and between areas of interest were significantly different ($F_{(4,16)} = 4.20$, $p<0.05$). The same was true for percentage fixations between AOI using the driving with and without distraction as the two conditions. The results for percent fixation were plotted in Figure 5.4 to show the differences in the percent of time that each area of interest were fixated. Though the degree of differences between the two conditions for the five groups varies, the results show that distraction considerably lessens the amount of visual fixation as drivers become more distracted while driving. The results however cannot be definitively established in which areas of interest becomes less fixated.

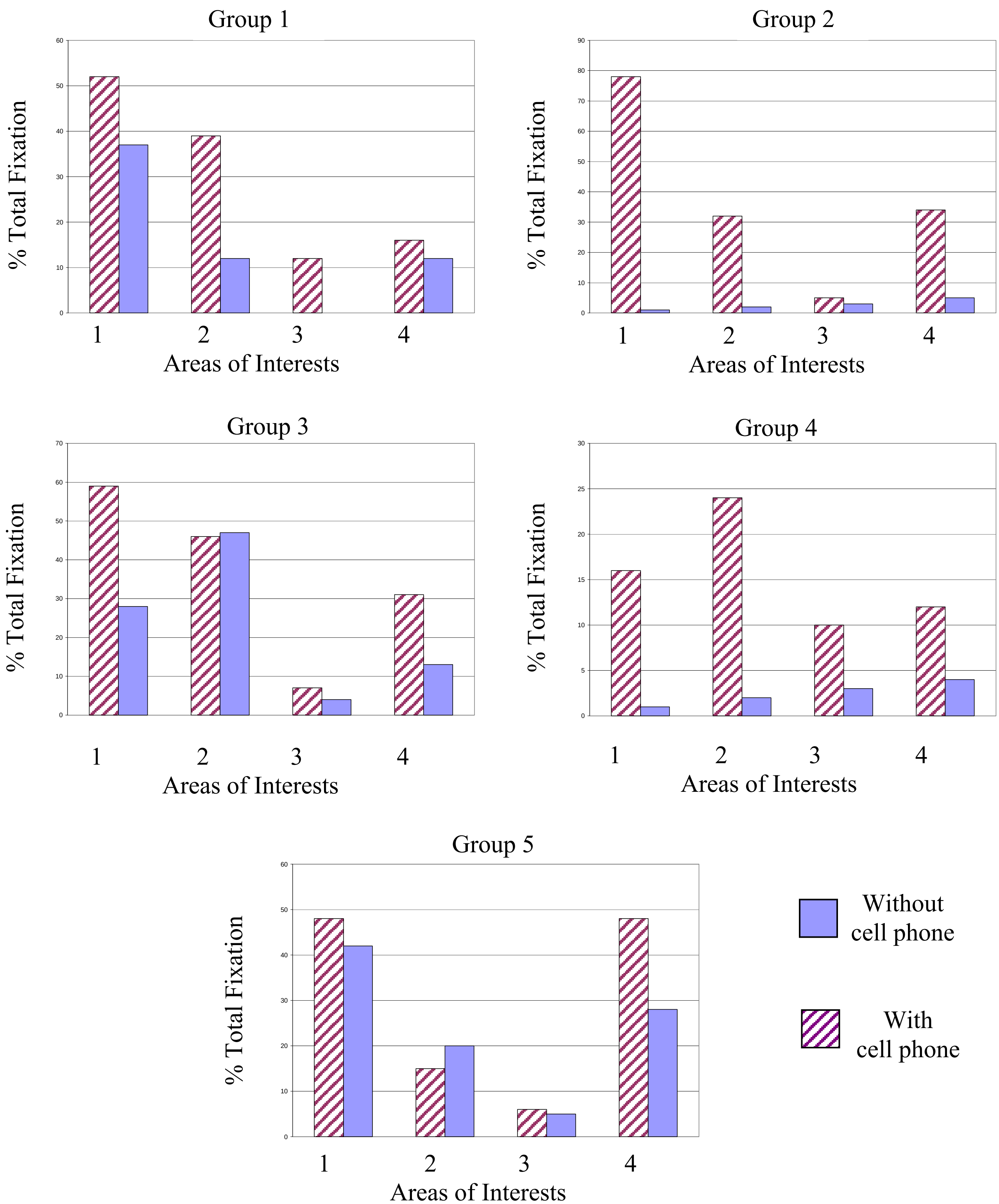


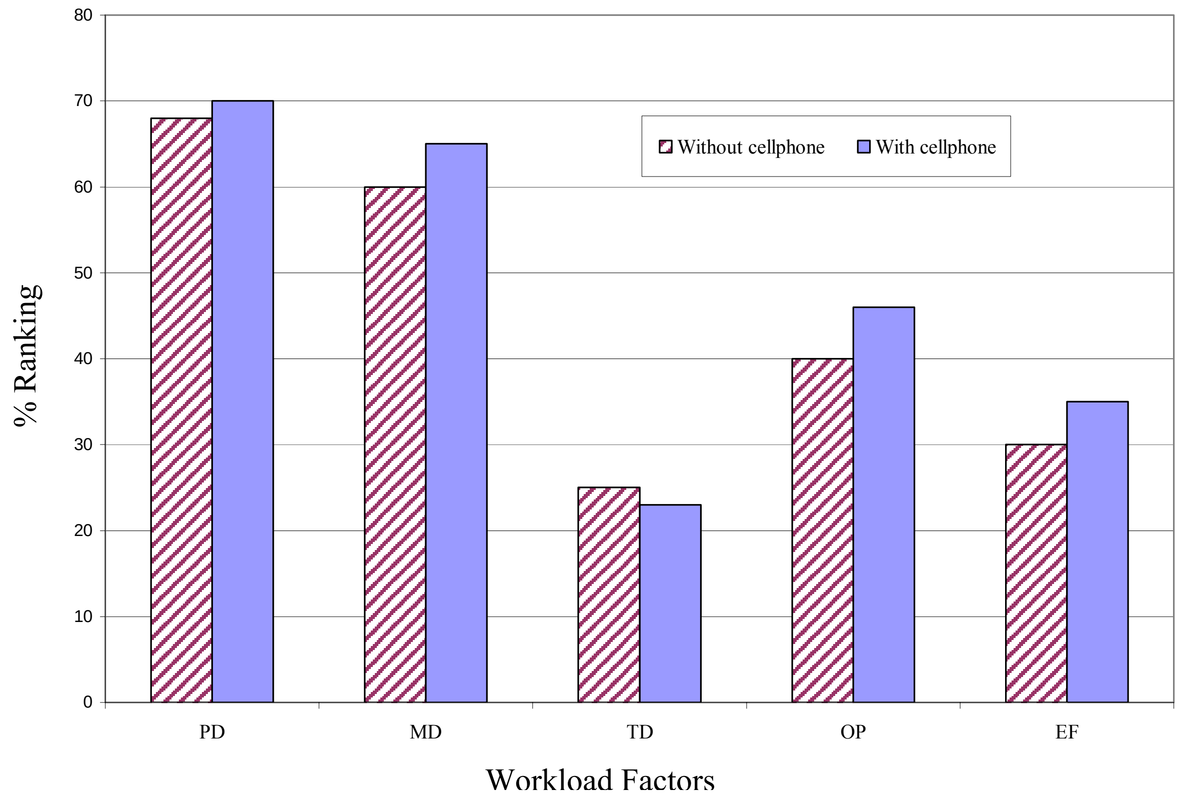
Figure 5.4. Comparison of percentage total fixation between groups for four areas of interest (1- Dashboard; 2- Left Side; 3 – Right Side; 4-Front/center).

5.3.4. Workload Assessment

The complexity of the workload is an important determination of the factors that affect the performance of participants. Different individuals have different perception of the degree of task complexity that affects their personal performance. Some are challenged by the mental task while others are challenged by its physical nature. Others can get easily frustrated while some have the inherent desire to exceed their own personal performance. The study assessed the participant's perception of the workload.

As the results of the driving elapsed time shows, all participants were not able to complete the assigned driving time when distraction is incorporated in the driving task. This is an interesting outcome as it indicates the difficulty experienced by the participants. In analyzing the complexity of the task, the NASA designed workload assessment instrument was used. The NASA Task Load Index (NASA TLX) is a multi-dimensional rating procedure that provides an overall workload score based on a weighted average of ratings on six subscales: Mental Demands (MD), Physical Demands (PD), Temporal Demands (TD), Own Performance (OP), Effort (EF), and Frustration (FR) (Appendix H). Three dimensions relate to the demands imposed on the subject (mental, physical. and temporal demands) and three to the interaction of a subject with the task (effort, frustration and performance). The degree to which each of the six factors contribute to the workload of the specific task to be evaluated, from the raters' perspectives, was determined by their responses to pair-wise comparisons among the six factors. Magnitude ratings on each subscale were obtained after each performance of a task. Ratings of factors deemed most important in creating the workload of a task were given more weight in computing the overall workload score, thereby enhancing the sensitivity of the scale. Figure 5.5 depicts the composition of a weighted workload score graphically. The first graph shows the assessment of workload based on rankings while the bottom graph shows the workload assessment based on ratings. The results indicate that ranking and rating of the six workload factors do not co-vary. For example, the physical demand has a high ranking for both driving conditions but low in ratings for participants driving with a cellphone. In this case, participants look at physical demand to be a primary source of workload in both conditions (68% to 70%) even though the demand is low (9% to 45%).

Furthermore, in interpreting the results above, it should be noted that the weight of the factors also matter. In the weight of the factors shown in the x axis, we can see that performance between the two conditions becomes less in terms of the degree to which it affected the drivers. Mental demand on the other hand increases in weight, i.e., in significance when cellular phone operation is added to the driving tasks. For driving with distraction, the results indicate a high mental demand with a group mean rating of 75%, constituting the biggest share of total workload of the task. It also registered a high ranking which indicates that participants looked at mental demand as a major source of workload. Temporal demand did not register high in both ranking and rating. This is quite peculiar as the experimental task was thought to be loaded with temporal demand that should make the participants feel pressured on time due to the rate or pace at which the tasks of driving and conversation occurred. The results can be attributed to the participant's unfamiliarity with the term temporal. The results also show very little frustration from the participants despite the inconvenience of wearing the eye tracking device and the limitations of the simulator.



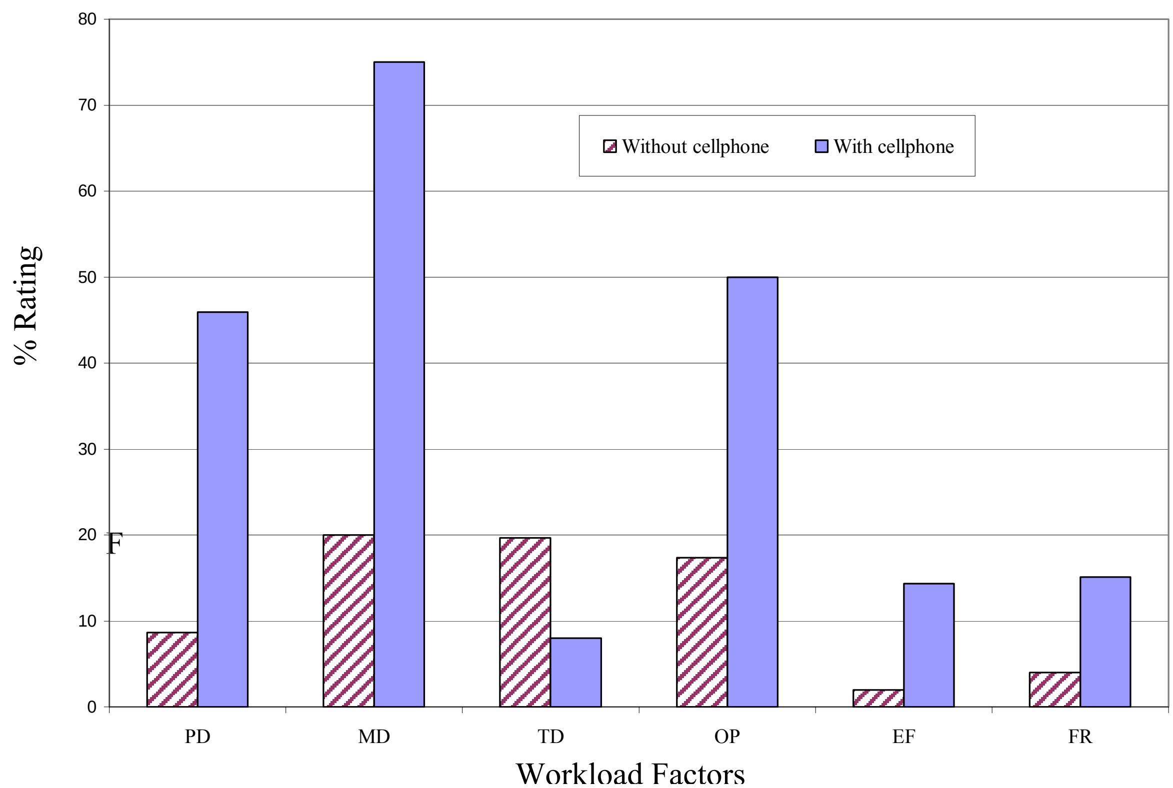


Figure 5.5 Results of NASA TLX ranking (top) and rating (bottom) of workload assessment for all groups.

To show the relationship between the subjective workload assessment and the performance of drivers, a total workload assessment for all groups were computed and plotted with the corresponding errors committed. This figure is shown below.

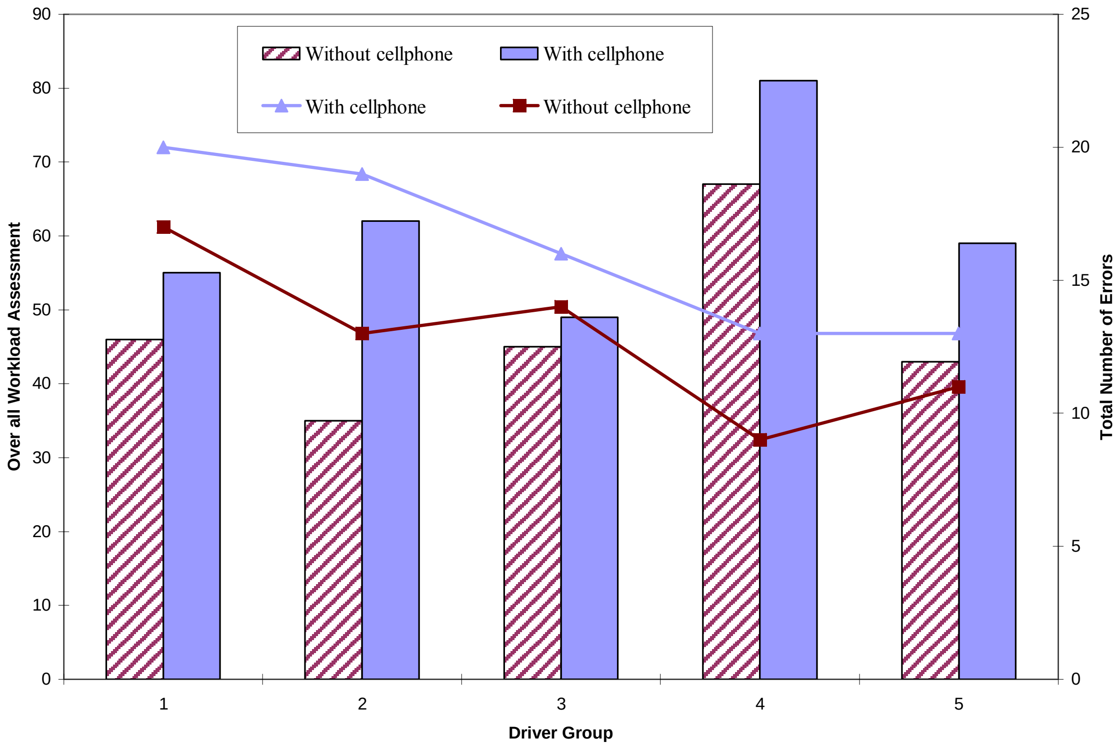


Figure 5.6. Total workload assessment (bars) and number of errors committed (lines).

The plot of workload assessment and errors committed shows that cellphone use was consistently rated to increase the workload of the task. The trend shows that an increase in the workload rating corresponds to the increase in errors committed. This trend was indicated with the exception of group 4 wherein there was a reduction of error that does not correspond to an increase in workload assessment. The same observation was noticed for both conditions of driving. The correlation between performance and workload factors were mixed. For example, comparing group 3 with group 4, indicated that there was a large increase in workload rating. This was an increase of 44% for nondistracted driving and 70% for distracted driving as rated subjectively by the participants in those groups. However, as indicated by the performance trend, the performance of group 4 was even better than group 3 in both conditions.

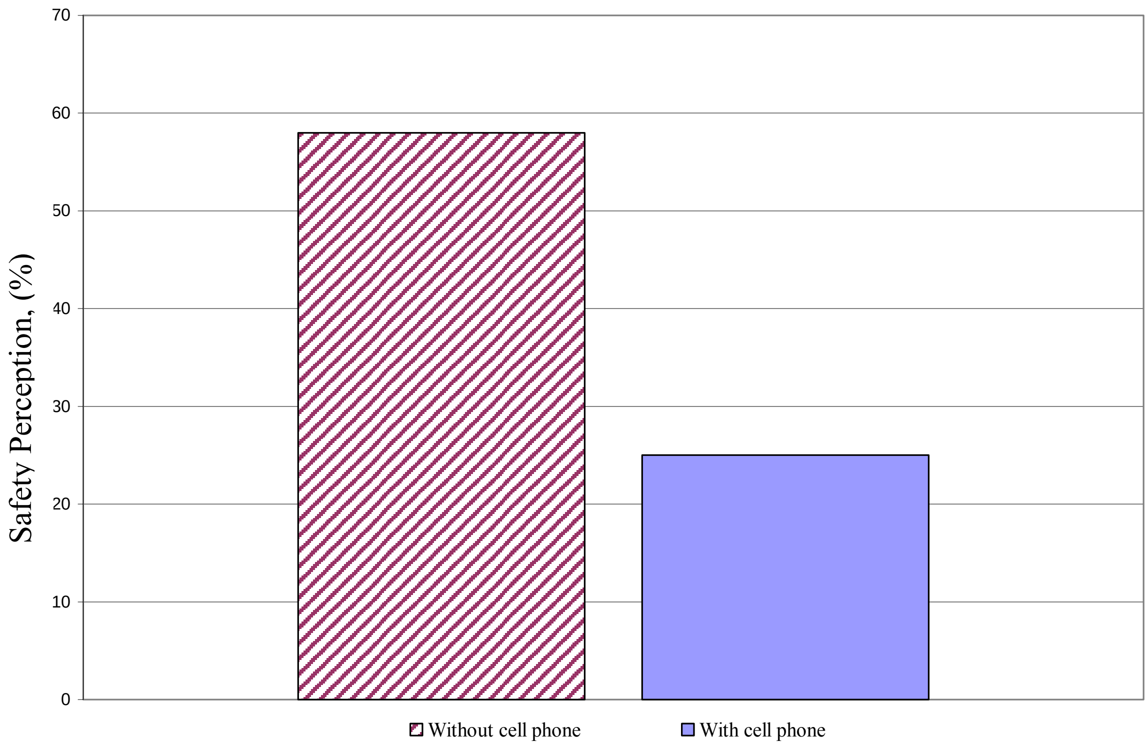


Figure 5.7. Comparison of overall perception of safety of all participants.

In addition to the NASA TLX workload assessment, a survey instrument was designed and used to assess the participants' perception of safety during the performance of both tasks. Figure 5.7 shows that the perception of safety decreased by about 56% when participants conversed using a cell phone while driving. From the results of the post experiment feedback, the main source of insecurity was the inability to concentrate on the primary task due to interruptions from the conversation, complexity of the driving, and the discomfort of wearing a head mounted eye tracking device.

5.4. Discussions

The task of operating a vehicle requires a complex behavior of extracting and assimilating the information from stimuli presented by the road conditions. The complexity is aggravated by the addition of other distracting tasks such as using a cellular phone. This may degrade the ability of the driver to produce a safe and efficient operation of the vehicle. In this study, the effect of distraction on driving using a combination of objective and subjective measures was described. The distraction used requires both physical and cognitive interruptions from the primary task of operating the vehicle.

The eye movement analysis used in the determination of fixation strategies and visual recognition was applied to drivers performing mental and physical tasks. The experiment showed that attention switching occurs and that different drivers have varying strategies in which they recognized objects and perceived their relationship to the current environment. More importantly, it illustrated that demand on attention and perceptions have different effects on eye movement and the ability drivers to respond to these demands. The effects of distraction are discussed below.

5.4.1. Drivers Performance and Visual Attention

The analysis of the relationship of driver's performance was based on the number of errors committed and visual attention. The results were based on the percentage of fixation on areas of interest and eye movement. The results showed an increase in the number of errors committed by the drivers that resulted to the deterioration of their performance. The deterioration increased as the complexity of the distraction increased. Driver's performances were measured based on the number of errors committed as well as the length of driving time. All of the participants who performed the cellular phone and driving tasks combination were not able to complete the tasks. It was shown in this experiment that fixation duration on significant objects becomes less as drivers operate the vehicle while performing additional cognitive as well as physical tasks. The reduction in fixation duration may have limited the cognitive abilities of the driver to evaluate and take corresponding actions. Anticipatory mechanisms that are a direct result of recognizing and understanding road sign and symbols (warnings, regulations, etc…) were impaired as the driver failed in his/her visual search while using a cell phone. As such visual fixation was not focused properly. An important point to consider in the downward performance level was the cognitive abilities of drivers driving under certain physical constraints.

The degradation of performance indicated also that visual attention based on fixation on objects and percentage viewing of objects decreases. Cognitive functions were believed to be reduced as increase in degree of tasks complexity occurs. However, this study did not measure cognitive abilities of drivers; as such no conclusive quantifiable description of cognitive function should be inferred from this study. The concentration of fixations on certain areas of interest in which durations are peculiarly longer than the rest points towards the psychophysical observation called visual tunneling.

5.4.2. Effect of Distraction on Eye Movement (Visual Tunneling Effect)

In visual perception research, the phenomenon of visual or perceptual tunneling, where in visual fixation is fixed on a single position, occurs for an extended amount of time determines the associated reduction in object detection from the visual stimuli In studying the effect of visual behavior given complex stimuli, the patterns of visual search may be influenced by the complexity of task brought about by quick changes in road conditions (Moray and Fitz, 1990). Results show that the perception of visual stimuli is complicated by the addition of interruptions. As shown from the figures of fixation and duration, there were significant differences in eye movement of drivers when using and not using a mobile phone conversation.

In Figure 5.1, it was shown that movements and position of the eye tends to be "stable." The stability can be seen with the concentration of fixation at certain locations for the duration of the driving task. At a certain point the stability is broken up by an occasional saccadic jump to other locations. On the other hand, a higher saccadic movement is observed for the driving condition without distraction. The steadier fixations for the former did not necessarily indicate a better perceptual ability than the latter as seen from the performance measures. It can only be inferred that since performances were lower for the distracted driving even at stable and more concentrated fixation, the perceptual ability was also affected. This finding can best be explained by the phenomenon of visual tunneling as suggested by Crundall, et al. (1999). Accordingly, tunnel vision describes the actual pattern of fixation due to a degradation of the functional field of view brought about by cognitive distraction. It suggests that there is actual shrinkage of the functional field with the furthest eccentricities suffering the most.

In this study, it can be seen that the most eccentric in terms of the field of view based on the calibrated visual scene were the left side view (AOI 3) and dashboard view (AOI 4). The cognitive distraction limits the ability to allocate the visual attention to the most significant view. In looking at the figure, we can see that the visual attention is focused on the center with abrupt changes (downward trend) as the use the mobile phone continues. The lack of visual fixation on the far peripheral view is a result of this limitation. Visual tunneling can also be inferred using the total percentage of viewing analysis. A subsequent object and visual attention analyses indicated the amount of time in percentage that each object was viewed for the two driving conditions were reduced. The reduction in percentage of viewing was a signature characteristic of drivers when additional tasks such as cellphone operation and continuous conversation were done simultaneously. The patterns of eye fixations were affected by the need to attend to the second tasks thus degrading the capability to allocate more time in viewing important objects in the road visual scenes. It had been experimentally demonstrated that the pattern of eye fixations reflects to some degree the cognitive state of the observer (Liu, 1998). If this was so, a stable fixation characterized by long duration was inferred to be an inattentive cognitive state.

Percentage analysis was also conducted in this study. This determined the fixations or gaze intersection with defined objects. The predefined objects were dashboard and control area, right side, left side and center views as mapped on the projector screen. This also provided an insight into the allocation of visual ability to deploy fixation. The allocation of deployment of visual capability depended largely on the amount of objects in the visual scene. In dynamic tasks such as driving, the presentation, i.e. appearance and disappearance of objects in the visual scene, limits the human visual capacity to fixate at each object for longer durations. The demand for fixation is large such that peripheral vision is relied upon to comprehend the whole picture. As it was observed, drivers focused only on a single stimulus and effectively search up to three targets per second (Moray, 1990). When a secondary task required visual resources such as fixations, a decrease in the amount of visual resources allocated to the driving task occurred (Rumar, 1998). The multiplicity of task posed a dangerous scenario for drivers as indicated by the causes of many major vehicular road crashes. Secondary tasks including the use of cellphones, pagers and other electronic communication devices have long been established as distractive to the critical task of driving. Studies have shown that even small conversation disrupts attentive scanning and visual fixation. McCarley, et al. (2004) suggested that the interference imposed by conversation was apparently not structural, but cognitive.

The highly specific visual behavior that drivers must exhibit as a result of attention grab by the objects in the driving scene, demonstrated the fundamentally active nature of vision. This meant that the more time the driver spent looking at the distraction or attending to tasks that are not related to the primary task, the more viewing distraction occurred leading to a reduction of driver's performance. This also suggested that in many situations a dynamic environment provided by driving poses difficulty in understanding the mechanisms that control the initiation of the different task-specific computations at the appropriate time. As concluded by Sato, et al. (2003), the visibility of traffic signs depends on active search according to an internally generated schedule, and this schedule depends both on the observer's goals and on learned probabilities about the environment. This means that perception of visual stimuli is affected by the dynamic presentation of the stimuli, the distraction associated with it and learning based on experience.

5.4.3. Task Complexity and Participants' Safety Perception

Two demands that were of particular interest to this experiment were physical and mental demand. Participants performing the two driving tasks rated physical demands on the performance differently. Surprisingly, physical demand was high on driving without cell phone than with cell phone. In the tasks performed, the driver rated the experiment based on how much physical activity was required (e.g., controlling the simulator, activating the cell phone,) or whether the task was easy or demanding, slow or brisk, slack or strenuous, restful or laborious.

The objective assessment on this particular workload showed the difficulty experienced by the driver operating the simulator while wearing a head mounted eye tracking device. This was also the results of the post experiment feedback interview conducted. On the other hand, the high rating on mental demand suggested that as the workload increases, so did the perception of workload. Mental demands include thinking (e.g. responding to questions), deciding, calculating, remembering, looking (e.g. object searching), and searching that required mental and perceptual activity. Other workload factors showed different experiences by the participants. For example temporal demands which measures how much time pressure did participants felt due to the rate or pace at which the tasks or task elements occurred showed even results. Performance and frustration for driving with cell phone is higher than driving without cellular phone.

Safety perception was gauged from these workload assessments. Over all, participants felt less safe when driving and using a cellular phone at the same time than concentrating on driving only. The insecurity, irritation and stress were expectedly higher in the former than the latter. The decreased in safety perception revealed the confidence of a successful accomplishment of the goal of the tasks set by the experimenter. Satisfaction was also rated low which may be attributed to operating the simulator than the experiment itself. In addition to this, discomfort was also rated high from the participant's feedback as can be expected since wearing a head mounted device was not something that any driver will do under normal circumstance.

5.4.4. Analysis Based on Two Group Combinations

In the second experiment, for driving with and without distraction, the two group combinations based on the Tukey-Kramer results indicated in Table 4.4 were also used. The groups compared were between a combination of groups 1, 2 and 3, and a combination of groups 4 and 5. The former is assigned as the infrequent drivers while the latter is assigned as frequent drivers. An analysis of the driving errors and fixation detection was done. The results are shown below.

5.4.4.1. Driving Errors Analysis

The specific errors committed by drivers of groups 1, 2 and 3 were combined. They were compared with the combined specific errors committed by groups 4 and 5. The results are shown in Figure 5.8. The results of the combination of groups 1, 2 and 3, and combination of groups 4 and 5 shows a decreasing trend in the amount of time where no fixation was detected. The frequent drivers have less time wherein they are not fixating on the visual screen. In both driving conditions, that is, the amount of time with no fixation detected was 58% when they are using the cellphone and 43% when they are not using the cellphone. The infrequent vehicle users have a total of 96% of time where no fixation where detected when not using a cellphone. When using a cellphone, the amount of time where no fixation was detected was 58%. The number of errors committed by those drivers who are using the cellular phone was higher than those who are not using the cellular phone. These results were in similar with the observation as describe previously despite the lower time of no fixation with cellphone than without cellphone. Frequent vehicle users in comparison with infrequent vehicle users have better control of the vehicle with distraction. Another interesting observation similar to the effect of distraction is the visual tunnel effect.

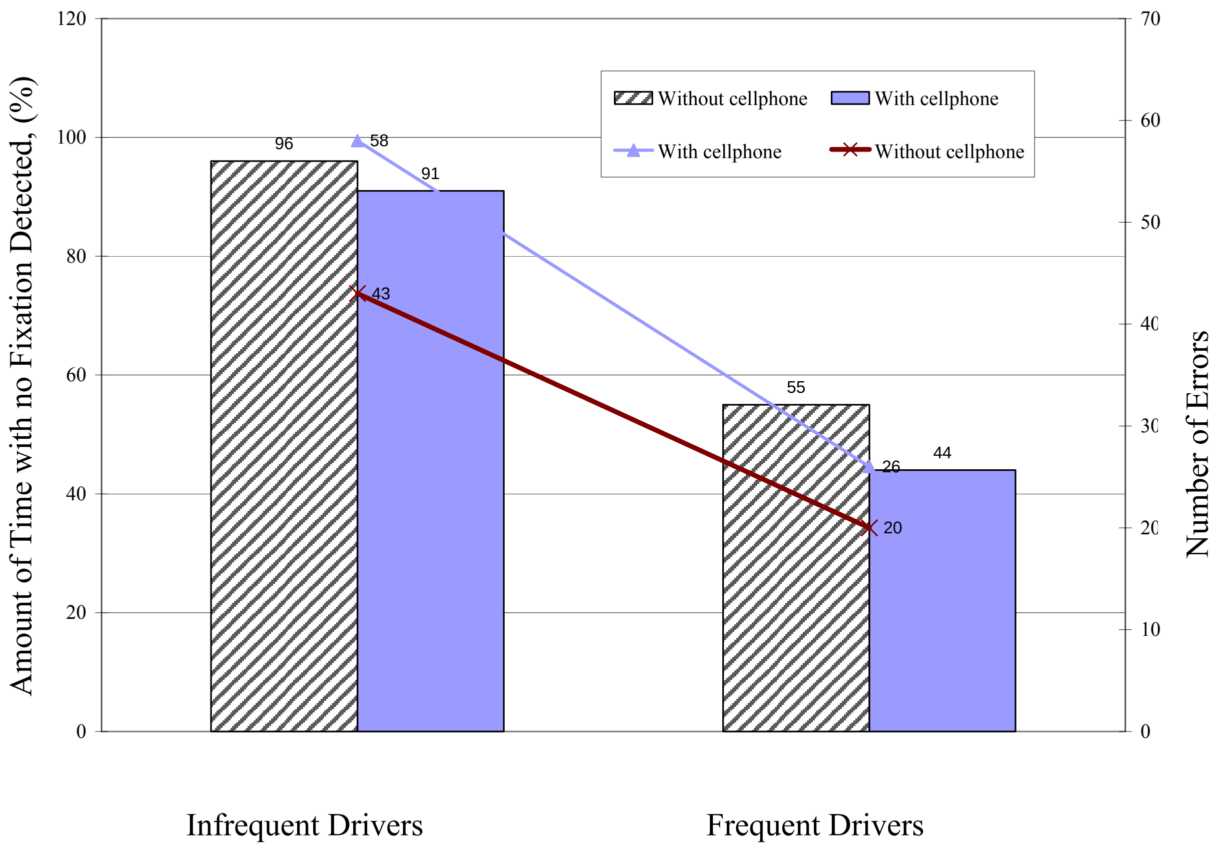


Figure 5.8. Number of errors (lines) and amount of time with no fixation detected (bars) for frequent and infrequent vehicle users.

The effect of visual tunnel is also observed even when the groups were combined and the results were compared. Higher number of errors was committed even when drivers of both groups have less time that they are not looking at the visual screen. The ability to perceive the objects when presented in a dynamic mode was made limited by the addition of secondary task. The secondary tasks put a demand on the mental and physical abilities of the drivers to respond to the stimulus. As such, errors where committed in higher numbers.

5.5. Conclusions

The basic method of analysis discussed here showed how a driver's attention is divided while performing the main task simultaneous with distractive tasks. The results showed that the degree of visual distraction contributed to the decline in driving performance. This was shown on the viewing percentage of objects of interest corresponding to different locations of driving scenarios projected on the screen. Performance of drivers deteriorates when using a mobile phone, from dialing to normal social conversation were simultaneously performed. Also the complexity of task interruptions affected visual attention in driving. The visual tunneling phenomenon was observed in the results. These were evident from the fixation duration for the two conditions studied. Gaze paths were steadier for driving with distraction than without distraction even though performance dropped in the former.

The reduction in performance relates to the use of limited cognitive processing abilities. This provided inference to a limited degree that these attention-grabs reduced cognitive functions and thus affect driving task. The dangers involved in reduce cognition was shown to continue as use of phone continued. This agreed with the situation described by Redelmeir and Tibshirani, in 1997, that the risk of cognitive conversation is still higher than "normal' after conversation ends. From the data collected, it was still however difficult to interpret cognitive risk since a cognitive task may also represent a glance at the road way. In this case it can also be said as unsafe driving practice. With this in mind one can appreciate that novice drivers are likely to be placed under considerable demands that frequent drivers can easily cope with. Future studies should pursue actual driving condition where real time distractions can be used together with other predetermined tasks such as operation of car radio system, use of navigational devices, and even a laptop computer.

The use of eye tracking device is seen as a useful tool to study visual distraction particularly in driving. However, wearing a head mounted device can not only be uncomfortable but does not simulate normal driving condition. Eye tracking studies in driving can also be used to determine the use of in vehicle eye tracking devices that detect abnormal or excessive visual distraction and errant eye gaze patterns that leads to higher risk for drivers and passengers alike.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The motivation for this study stemmed from the increasing vehicular accidents related to the prevalent use of in-vehicle technologies while driving and the seemingly insufficient and ineffective implementations of guidelines with regards to their use. Driving requires visual ability; therefore, it is only logical to determine the impact of the different factors that affect visual behavior when driving. The results of past studies vary as the technology for eye tracking continues to improve in accuracy and precision. The lack of a comprehensive studies dealing with visual behavior and driving have forced many researchers to rely simply on passive observations. For example, using vehicle mounted video monitors to record the vehicle and the driver. The results were then used to correlate the causes of accidents related to driver distraction. Little statistical evidence provided credence on the many implications of distraction resulting in the hesitation of many countries to make legislations related to the use of in vehicle technologies.

This research studied the visual behavior in a simulated driving task. The main objective of this research was to study some of the implications of demands to human's attention and perception and how it affects performance of task such as driving. Specifically, the study aimed to determine the changes that occur in the visual behavior of drivers with different levels of driving frequency by tracking the movement of the eye. Two experiments were conducted in this study. In the first experiment, the effects of different levels of task complexity on visual fixation strategies and visual stimulus recognition were examined. The effects of secondary task on attentional and visual focus and their impacts on driving performance were investigated in the second experiment. The implications of the use of information technology device (cellular phone) while driving on road safety were subsequently evaluated. In this research, an experiment that recorded eye movement under simulated driving conditions using a head mounted eye tracking device was conducted. The research was intended to provide objective evidence of the changes in visual behavior of driver. Two experiments were conducted to evaluate the effects of several driving factors in visual behavior and how they affect the safety of the driver. Eye movement was measured to provide a quantifiable data that formed the basis of the conclusions of this study. The conclusions were based on results of the drivers who where grouped according to the frequency by which they used their vehicle in a week. The results of the statistical analyses on the individual driving frequency differences were evident only between the first group and the fifth group or when a combination of groups 1, 2, and 3 were compared with the group combining 4 and 5. As such, the discussion of the results is limited into comparing the infrequent vehicle users (groups 1, 2, and 3) frequent vehicle users (groups 4 and 5). These conclusions are discussed below.

6.1.1. Differences in Visual Behavior of Drivers with Varying Levels of Driving Experience at Different Driving Conditions.

In the first experiment, several conclusions were drawn. These were:

- Differences in visual behavior of drivers exist. This was shown in the fixation analysis of both patterns of eye movement and frequency of fixations wherein drivers who are infrequent users of vehicle fixated more on the dashboard area (36.33%) than on the front and center view (14.33%). In contrast, the frequent drivers have higher fixations that were recorded on the front and center (39.5%) as compared the dashboard area (12%). Such behavior of frequent driver allowed for peripheral vision to be utilized increasing the functional field of view. The same trend was seen for complex driving but with lower percentage of total fixations than the simple driving conditions.

- As the complexity of driving condition increased that is as more objects that increase the demand for visual allocation were presented, visual behavior changed. Drivers who use their vehicle frequently were able to cope with the demand better the infrequent counterpart of drivers. The results for all participants showed a reduction in fixation frequencies and an increased in gaps between fixations. These indicated that an increase in demand led to a reduction in the allocation of visual ability.
- Despite the differences in visual behavior, all drivers were able to view or fixate the significant objects in the visual scene. The effectiveness of the fixation was more evident for the frequent driver. The match between verbal report and actual fixation location was higher for the frequent vehicle users (87.75%) as compared to the infrequent vehicle users (70.56%). Higher match rates indicated a better control of the vehicle and efficient allocation of visual ability.
- Corollary to the complexity of driving condition, an increased in saccadic jump was also observed. A 27% reduction in saccades between frequent vehicle users and infrequent vehicle users. A 12.8% increase in saccadic frequency was observed between simple and complex driving conditions was

observed. Saccadic jumps showed the effect of complexity of driving. This also reflected the attempt of participants to properly allocate visual fixation on the objects that appear. Clearly, as more objects were presented, drivers tend to fixate on most of the objects.

- The reliability of using eye tracking to measure eye movement still needs improvement in terms of accuracy and precision. The percent match between fixation location and drivers' verbal reports show that measurement of visual fixation does not correspond to the observer's view. The verbal report method also added to the workload that affects drivers' visual behavior and consequently their performance.

6.1.2. The Effect of Driving with Secondary Tasks on Visual Behavior and Driving Performance.

The performance of the main task simultaneous with distractive tasks showed how driver's attentions were affected. The performance of demanding tasks while driving produced effects on visual behavior, performance, and safety perception. Primarily, these conclusions were drawn in this study.

- The degree of visual distraction contributes to the decline in driving performance. Performance of drivers deteriorated to as much as 55% as participants use mobile phone, from dialing to normal social conversation was simultaneously performed.
- Though a higher duration of fixation with less saccadic jump were observed, driving with secondary tasks led to higher number of errors committed. This indicated ineffective perception of the objects attributed to visual tunneling.

- Fixation durations while driving were reduced in two of the four areas of interest with the addition of secondary tasks. This suggested the detrimental effects of conversation on performance. Higher time where no fixation was measured or detected was observed when driving and using a cellphone. The distraction accounts for a reduction of visual fixation from 96% to 91% for the drivers with less frequency of vehicle use and 55% to 44% for driver's with more frequent use of vehicle. This conclusion was drawn based on the results showing limited time available for perceptual analysis and saccade planning.
- The complexity of task interruptions also affected visual attention in driving. The reduction in performance was related to the use of limited cognitive processing abilities. With this in mind, one can appreciate that novice drivers are likely to be placed at higher risk and under considerable demands that experienced drivers can easily cope with.

6.2. Implications

This research evaluated the visual behavior of driver by measuring eye movement in a simulated driving condition. Several variables were used to determine their effects on eye movement. There are theoretical and practical implications that can be used in the future.

6.2.1. Theoretical Contributions

Primarily, this research showed the use of eye movement tracking in quantifying visual behavior. Since most of the theoretical models of human visual cognition were based on subjective measures, a measurable quantity provides a strong supplement to the validity of the cognitive models. This will allow for a better evaluation of human visual and driving performance. The research also provides a baseline study that in the future will aid in developing systems that mitigate the detrimental effects of using cellular phone as well as other secondary tasks while driving.

Other than driving, the results of this study can also be extended in other domain such as user interface evaluation. The continued development that improves the eye tracking technology will allow more accurate and precise measurement of eye movement. In human-computer interface design and evaluation, eye tracking is expected to be faster than existing pointing device such as the computer mouse once the technology has improved on its accuracy and tracking ability. When this occurs it would also allow for hands free typing and other haptic type of interaction with interfaces such as the mouse, touchpad and joystick.

6.2.2. Practical Contributions

The study also provided some practical contributions. The results added some measure of strength to the argument that secondary tasks such a using a cellular phone while driving have detrimental effects on the driver's ability to perform the driving task. These results were based on objective data in contrast to subjective and passive observations of the causes of vehicular accidents.

The analysis of fixation results, i.e. pattern and frequency, can be used to design car interfaces and controls as well as road signs and symbols. Results showed when, where and how long do participants look at certain objects on the road and dashboard areas at different conditions. For example, a head up display configuration of controls is the more applicable display, since some groups would concentrate on front and center rather than dashboard.

The most significant practical contributions of this research are its implication to safety. Using this study, one can now argue, to a certain degree, that when engaged in intense tasks, drivers do not scan the road as much as they do otherwise. Under normal conditions, if drivers over scan the visual scene, then factors of safety are affected. If they do not over scan then the reduction is conceivably detrimental. Eye tracking studies in driving may also be used to determine the use of in vehicle eye tracking devices that detect abnormal or excessive visual distraction and errant eye gaze patterns that leads to higher risk for drivers and passengers alike. With regards to frequency of vehicle use, the results suggest that dual-task performance interfere with the primary task of driving. This may be especially harmful particularly for novice driver's performance in real-world circumstances.

6.3. Limitations of the Study

The study that was conducted and the conclusions drawn were limited by several factors that affect the results obtained. The most significant limitations were due to the equipment used in the experiment. The eye tracking machine and driving simulator pose several limitations on their use in experimental conditions.

6.3.1. Eye Tracking System

An accurate, reliable, and robust eye tracking reports of where the eye is focusing in space from moment to moment is essential. Though there have been significant improvement with regards to the technology, some limitations still exist. With regards to the experiment conducted, the main limitation in eye tracking measurement with respect to the devices used is the accuracy of results and stability of the mounting of the device to the head. The technology on head mounted eye tracking device that was used in this study used the dark pupil system wherein the eye is illuminated by infrared light. Since the infra red light source is placed at some fixed position relative to the eye, the stability of head and eye tracking is imperative. Slight movement of the device after the calibration would cause changes in reference point thereby making inconsistent eye tracking measurement. To eliminate such movement, the device's fitting straps should be fitted tightly which will bring about discomfort to the participant. This limitation was observed several times during the experiment wherein participants reported a movement of the device thus the difficulty of establishing a good calibration. The calibration process is critical to an accurate eye movement measurement in this study. The need for constant drift correction was necessary to make sure that eye position relative to the device has not change. However, drift correction is impractical and inconvenient especially for experimental conditions that require longer task durations. This interrupts the participants performance and behavior which may have affected the results. Also, due to the fact that the shape of the human eye is a variable, no calibration was made for some participants because the device was unable to locate the eyes on certain individuals. In some cases, the eye tracking device is unable to keep track of eye movement continuously. Lastly, for some participants, wearing the eye tracking device is inconvenient and obtrusive.

6.3.2. Simulated vs. Actual Driving

A simulated condition is ideal for experimental purposes because conditions can be controlled at much leverage. However, results are limited by the fact that realistic conditions do affect the results of eye movement measurement as in the case of this study. Simulated driving is controlled where general driving condition is sometimes unrealistic. Some driving interfaces do not exactly match actual vehicle interface. In the case of the simulator used, the controls for left and right turn, left, right, and rear mirrors require activation of the computer keyboard. These are obviously not the case for actual driving. Situational awareness of the driving environment is different in simulated driving. The screen projection may not stimulate the proper participant's behavioral inclinations as opposed to actual driving. This limits any extension of the discussion of the results to real time driving condition.

6.4. Recommendations for Future Research

In many cases, scientific discoveries are built upon not only from single research endeavor, but also though the collective and collaborative efforts of the entire scientific community. This study was conducted in the hope of making a contribution to this effort, if only in providing some insights into future research directions. Society and technology are continuously changing. Both adapt to each other and in many ways affect one another. Under these circumstances, this study suggests some areas for future investigations on the effects of multi-tasking and eye movement measurement in driving.

- Use actual on-road driving, instead of simulated driving. This will effectively extend the results to real life situations, as well as make for more convincing argument to the general population.
- Pursue studies that evaluate the effects of other secondary tasks (distractions) that can be used together with other predetermined tasks, such as operation of car radio system, use of Global Positioning System, and other navigational aid devices.

- The use of eye tracking device is seen as a useful tool to study visual distraction particularly in driving. However, wearing a head mounted device not only is uncomfortable, but also does not simulate normal driving condition. Use of other device that are less obtrusive (e.g. eye tracking device in an eye glass configuration) are highly recommended.
- Other driving conditions that influence driving behavior should be studied. These include but are not limited to environmental conditions such as day or night driving, weather related conditions, and other driving scenarios.
- Other factors related to studies dealing with human participants should be considered in human performance evaluations. These include but are not limited to gender, age, and general physical well being prior to the study.

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APPENDIX A

PARTICIPANT RECRUITMENT ANNOUNCEMENT

Hi !

My name is Larry Nabatilan. I am a graduate student working on my dissertation entitled:

FACTORS THAT INFLUENCE VISUAL ATTENTION AND THEIR EFFECTS ON SAFETY IN DRIVING: AN EYE MOVEMENT TRACKING APPROACH

In this experiment participant will perform a driving simulation task under several conditions. If you are interested please contact me at:

CEBA Rm 3402
Tel No. (225)- 578-4848
Email: Lnabat1@lsu.edu

Schedule of experiment is as follows:

Day: Monday, Wednesday or Friday
Time: 9 to 10:30; 11 to 12:30; 1 to 2:30 or 3 to 4:30

TIME	**MONDAY**	**WEDNESDAY**	**FRIDAY**
9:00 – 10:30			
11:00– 12:30			
1 :00 – 2:30			
3:00 – 4:30			

You may also set other schedule by appointment.

Thank you !

APPENDIX B

CONSENT FORM

LOUISIANA STATE UNIVERSITY
Construction Management and Industrial Engineering
CEBA Rm. 3402, Human Factors Laboratory

(Please read the form carefully and ask questions about the purpose of the research, procedures, the possible risks and benefits, your rights as a volunteer and anything else about the research or this form that is not clear)

CONSENT FORM

Modeling of Attentional and Perceptual Demands on Driving Performance: An Eye Movement Tracking Approach

PURPOSE AND BENEFITS

The goal of this study is to investigate the impact of visual distraction on the risk of vehicular accidents by developing a visual attention processing model. This model will describe the strategy by which drivers establish their visual behavior and explain cognitive elaboration using eye movement measurement as indicators.

PROCEDURES

The experiment will take approximately 60 minutes. It consists of three sessions During the first session participants will be asked to answer questions relating to driving experience. In sessions two and three, the participants will wear a head mounted eye tracking device which is similar to an ordinary bicycle helmet with two cameras attached. Session two involves practice and calibration. The third session involves three driving tasks in which participants will be asked to perform different driving maneuvers using the laboratory driving simulator.

RISKS, STRESS OR DISCOMFORT

The possible risks of participating in the study are minor muscle fatigue and eye tiredness.

OTHER INFORMATION

If the results of the present study will get published, names or identifying information of the subjects will not be included in the publication. Subject identity will remain confidential unless disclosure is required by law. The data will be stored in a locked cabinet or password-secured computer. The screening questionnaires of rejected subjects will be destroyed.

RESEARCHERS AND CONTACT INFORMATION

Name	Title	E-mail	Phone #
Dr. Fereydoun Aghazadeh	Associate Professor	aghazadeh@lsu.edu	578-5367
Larry B. Nabatilan	PhD Student	Lnabat1@lsu.edu	578-4848

SUBJECT'S STATEMENT

The study procedure has been completely explained to me and all my questions have been answered. I have understood the procedure and if I have additional questions regarding study specifics I may direct them to investigator. If I have questions about subject's rights or other concerns, I can contact Robert C. Mathews, Institutional Review Board, at (225) 578 – 8962. I agree to participate in the present study and acknowledge the investigators obligation to provide me with a signed copy of this consent form.

________________________ ________________________ ______________

Printed Name Signature Date

APPENDIX C

IRB APPLICATION

LOUISIANA STATE UNIVERSITY – BATON ROUGE CAMPUS
CONSENT FORM

1. Study Title	Modeling of Attentional and Perceptual Demands on Driving Performance: an Eye Movement Tracking Approach
2. Performance Site	CEBA, Rm. 3402 Human Factors Laboratory Department of Construction management and Industrial Engineering, Louisiana State University, Baton Rouge, 70808, Louisiana
3. Investigators	The following investigators are available for questions about this study: Dr. Fereydoun Aghazadeh Associate Professor Department of Construction Management and Industrial Engineering 3123B CEBA Bldg. Louisiana State University Baton Rouge, LA., 70803 Tel. No.: (225) 578-5367 Larry B. Nabatilan PhD Student Department of Construction Management and Industrial Engineering 3402 CEBA Bldg. Louisiana State University Baton Rouge, LA., 70803 Tel. No.: (225) 578-4848
4. Purpose of the study	The uses of eye movement and tracking have been the subject of many research activities. Despite decades of research, the role of gaze in car driving is still poorly understood (Rogers, 2005). In the light of these developments in technology, it is still a fairly debated issue as to how humans process information. Understanding these concepts will reveal a lot on making an effective use of visual perception to cognition of information. This thesis proposes to define the underlying dimensions

of visual distraction that affects performance of tasks specifically when operating a vehicle. The goal of this study is to investigate the impact of visual distraction on the risk of vehicular accidents by developing a visual attention processing model. This model will describe the strategy by which drivers establish their visual behavior and explain cognitive elaboration using eye movement measurement as indicators. The primary goal of this research is the development of empirical model that will explain the impact of driver distraction on driving performance using eye movement tracking measurements.

5. Subject Inclusion

Graduate and undergraduate students at Louisiana State University will be asked to participate in this experiment. Subjects who answered "YES" to any of the questions will be excluded from this research.

1. Do you have a history of any of the following?
    a. Visual Impairment?
    b. Hearing Impairment?
    c. Seizures or other lapses of consciousness?
    d. Any other disorders that would impair your ability to drive?

2. Have you, in the last 24 hours, experienced any of the following conditions?

Inadequate sleep?	YES	NO
Unusual hunger?	YES	NO
Hangover ?	YES	NO
Headache ?	YES	NO
Cold Symptoms?	YES	NO
Depression ?	YES	NO
Allergies ?	YES	NO
Emotional upset?	YES	NO

3. Did you take alcohol within the last 24 hours?

6. Number of subjects

Fifty (50)

7. Study Procedures

The experiment consists of three sessions. During the first session participants will be asked to answer questions relating to driving experience. Session two involves practice and calibration. Practice sessions for each experiment and for all driving scenarios will be performed by the subject to acquaint him/her on the driving consoles and to acclimatize the driver on driving with head mounted eye tracking device. During calibration, the subject is presented with a number of targets in known locations. In this study, all participants will perform the eye tracking calibration in order to measure eye movement parameters. The third session involves three driving tasks in which participants will be asked to perform different driving maneuvers using a driving simulator in the laboratory. Participants will wear a head mounted eye tracking device which is similar to an ordinary bicycle helmet with two cameras attached. This device will measure any eye movement that the participants will make. Hence the basic purpose of this research is to measure eye movements of the participants with respect to the performance of the driving tasks.

8. Benefits

There will not be any direct health, monetary or mental benefits to the individual participant. The study however may be beneficial to the greater population as it leads to a better understanding of how distraction whether visual or cognitive affects our driving behavior. This study may also provide some basis for developing mitigating measures that may reduce the risk of vehicular accidents.

9. Risks

The possible risks of participating in the study are muscle fatigue and eye tiredness/stress.

10. Right to Refuse

Subjects may choose not to participate or if any time during the study, subject feels discomfort with any method or performing requirements, formal withdrawal from the study will commence at any time without penalty.

11. Privacy

If the results of the present study will get published, names or identifying information of the subjects will not be included in the publication. Subject identity will remain secret unless disclosure is required by law. The data will be stored in a locked cabinet or password-secured computer. The screening questionnaires of rejected subjects will be destroyed.

12. Financial Information

Subjects are volunteers and will not be compensated for participation in this study

Institutional Review Board
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Louisiana State University and A&M College
Baton Rouge LA 70803

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INSTITUTIONAL REVIEW BOARD

ACTION ON PROTOCOL APPROVAL REQUEST

TO: F. Aghazadeh
Department of Construction Management and Industrial Engineering

FROM: Robert C. Mathews
Chair, Institutional Review Board for Research with Human Subjects

DATE: February 06, 2006

RE: **IRB#** 2611

TITLE: "Modeling of Attentional and Perceptual Demands on Driving Performance: An Eye Movement Tracking Approach"

New Protocol/Modification/Continuation : N

Review type: Full _____ Expedited X **Review date:** 02/02/2006

Risk Factor: Minimal X Uncertain _____ Greater Than Minimal _____

Approved X **Disapproved** __________

Approval Date: 02/02/2006 **Approval Expiration Date:** 02/02/2007

Re-review frequency: (annual unless otherwise stated) _____

Number of subjects approved: 50

By: Robert C. Mathews, Chairman Robert C Mathews

Study approved by
Louisiana State University
Institutional Review Board
203 B-1 David Boyd Hall
225-578-8692
Robert C. Mathews, Chair
Approval Expires 2/2/2007

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING -- Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. SPECIAL NOTE:

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.fas.lsu.edu/osp/irb*

APPENDIX D

PRE-SCREENING QUESTIONNAIRE

Screening Questionnaire and Background Information

Participant's Name: ________________________

Gender: (1=M, 2=F) Age: ___________________

Please answer the following questions.

1. Do you possess a valid driver's license? YES NO

2. How many times per week do you drive?
   4 + 2 -3 X 1X <1X

3. Approximately how many miles do you drive per week?
   Under 20 20 – 30 30 – 50 50 – 70 100 or more

4. What type of automobile do you drive most often?
   Standard Size MiniVan SUV Truck

5. What level of education have you reached? (Check only one)
   ____Current Undergraduate Student
   ____College Degree
   ____Some Graduate Work
   ____Completed Masters Degree
   ____Completed Doctorate
   ____Post-Doctorate Work

7. Are you in good general health? YES NO
   Do you have a history of any of the following?

   Visual Impairment ? YES NO
   (If yes, please describe) ____________________________________

   Hearing Impairment ? YES NO
   (If yes, please describe)____________________________________

   Seizures or other lapses of consciousness? YES NO
   (If yes, please describe)____________________________________

   Any other disorders that would impair your ability to drive? YES NO
   (If yes, please describe)____________________________________

9. Have you, in the last 24 hours, experienced any of the following conditions?

Inadequate sleep?	YES	NO	Cold Symptoms?	YES	NO
Unusual hunger?	YES	NO	Headache ?	YES	NO
Hangover ?	YES	NO	Allergies ?	YES	NO

10. Did you take alcohol within the last 24 hours? YES NO

11. Do you own a cellular phone? YES NO

12. If you own a cellular phone, how often do you use it when driving?

1	2	3	4	5	6	7
Not At all						Always

13. Have you been involve in road mishaps while using your cell phone ?

YES NO

14. Have you used a PC-Based simulation program? YES NO

If YES, please specify ______________________________

15. Do you like playing PC based simulation games?

1	2	3	4	5	6	7
Not At all						Very Much

15. How often do you play a simulation game per day?

Less than 1 hour 2 -3 hours 3 – 4 hours 4 – 5 hours More than 5 hours

APPENDIX E

SAMPLE RAW EYE MOVEMENT DATA

Sample Raw Eye Movement Data

Time	R CR1 X	R CR1 Y	Time	R POR X	R POR Y	Timing	Latency	Frame
3.59E+09	126.99	116.47	3.59E+09	-223.21	105.37	0	3116	00:00:28:11
3.59E+09	126.94	116.46	3.59E+09	-220.57	17.99	0	3067	00:00:00:01
3.59E+09	126.99	116.46	3.59E+09	-212.68	1.69	0	3208	00:00:00:01
3.59E+09	127	116.32	3.59E+09	-212.24	91.76	0	3163	00:00:00:02
3.59E+09	127	116.32	3.59E+09	-231.22	-15.18	0	3156	00:00:00:02
3.59E+09	127.12	116.25	3.59E+09	-183.16	233.39	0	3075	00:00:00:03
3.59E+09	127	116.25	3.59E+09	-235.05	-82.42	0	3187	00:00:00:03
3.59E+09	127.12	116.25	3.59E+09	-206.12	46.25	0	3128	00:00:00:04
3.59E+09	127.01	116.25	3.59E+09	-220.36	-87.07	0	3093	00:00:00:04
3.59E+09	127.13	116.25	3.59E+09	-225.69	31.08	0	3152	00:00:00:05
3.59E+09	127.06	116.28	3.59E+09	-232.77	-106.75	0	3149	00:00:00:05
3.59E+09	127.13	116.28	3.59E+09	-198.14	138.27	0	3066	00:00:00:06
3.59E+09	127.01	116.25	3.59E+09	-230.98	28.46	0	3059	00:00:00:06
3.59E+09	127.12	116.25	3.59E+09	-201.74	11.26	0	3089	00:00:00:07
3.59E+09	127.01	116.25	3.59E+09	-214.33	-48.26	0	3132	00:00:00:07
3.59E+09	127.12	116.25	3.59E+09	-220.89	-60.13	0	3174	00:00:00:08
3.59E+09	127	116.25	3.59E+09	-254.62	-32.45	0	3115	00:00:00:08
3.59E+09	127.06	116.23	3.59E+09	-208.56	-5.54	0	3072	00:00:00:09
3.59E+09	127	116.22	3.59E+09	-240.55	-36.69	0	3031	00:00:00:09
3.59E+09	127.06	116.22	3.59E+09	-211.35	-28.83	0	3143	00:00:00:10
3.59E+09	127.01	116.22	3.59E+09	-258.68	-20.9	0	3127	00:00:00:10
3.59E+09	127.07	116.15	3.59E+09	-236.57	14.44	0	3114	00:00:00:11
3.59E+09	127	116.15	3.59E+09	-218.53	-51.45	0	3079	00:00:00:11
3.59E+09	127.14	116.17	3.59E+09	-204.31	173.1	0	3095	00:00:00:12
3.59E+09	127.01	116.17	3.59E+09	-225.37	-107.22	0	3080	00:00:00:12
3.59E+09	127.14	116.17	3.59E+09	-206.28	171.99	0	3143	00:00:00:13
3.59E+09	127.01	116.17	3.59E+09	-246.49	-28.64	0	3124	00:00:00:13
3.59E+09	127.07	116.03	3.59E+09	-212.66	143.37	0	3109	00:00:00:14
3.59E+09	127.01	116.03	3.59E+09	-223.15	-93.66	0	3163	00:00:00:14
3.59E+09	127.05	116.03	3.59E+09	-212.69	86.41	0	3227	00:00:00:15
3.59E+09	127	116.03	3.59E+09	-217.48	-3.33	0	3117	00:00:00:15
3.59E+09	127.06	116.22	3.59E+09	-242.27	-10.66	0	3082	00:00:00:16
3.59E+09	127	116.22	3.59E+09	-232.65	26.75	0	3100	00:00:00:16
3.59E+09	127.14	116.09	3.59E+09	-235.57	69.62	0	3113	00:00:00:17
3.59E+09	127.01	116.09	3.59E+09	-223.71	55.31	0	3057	00:00:00:17
3.59E+09	127.06	116.46	3.59E+09	-208.82	18.06	0	3046	00:00:00:18
3.59E+09	127.19	116.53	3.59E+09	-206.8	42.5	0	3106	00:00:00:18
3.59E+09	127.34	116.4	3.59E+09	-184.12	94.2	0	3143	00:00:00:19
3.59E+09	127.62	116.43	3.59E+09	-181.88	77.65	0	3154	00:00:00:19
3.59E+09	127.67	116.56	3.59E+09	-180.19	139.46	0	3099	00:00:00:20
3.59E+09	127.77	116.57	3.59E+09	-191.72	0.53	0	3085	00:00:00:20
3.59E+09	127.93	116.57	3.59E+09	-191.42	16.8	0	3064	00:00:00:21
3.59E+09	127.79	116.57	3.59E+09	-194.05	50.67	0	3105	00:00:00:21
3.59E+09	127.94	116.57	3.59E+09	-211.96	134.48	0	3154	00:00:00:22
3.59E+09	127.99	116.47	3.59E+09	-206.22	-12.36	0	3157	00:00:00:22
3.59E+09	127.95	116.47	3.59E+09	-217.99	13.69	0	3128	00:00:00:23

3.59E+09	128.97	116.53	3.59E+09	-179.82	136.91	0	3047	00:00:00:23
3.59E+09	129.17	116.5	3.59E+09	-167.61	40.58	0	3059	00:00:00:24
3.59E+09	129.07	116.46	3.59E+09	-168.02	-42.66	0	3054	00:00:00:24
3.59E+09	129.08	116.5	3.59E+09	-160.28	103.22	0	3175	00:00:00:25
3.59E+09	129.22	116.58	3.59E+09	-161.95	12.78	0	3140	00:00:00:25
3.59E+09	129.23	116.58	3.59E+09	-145.95	65.26	0	3157	00:00:00:26
3.59E+09	129.23	116.58	3.59E+09	-153.98	37.78	0	3148	00:00:00:26
3.59E+09	129.37	116.58	3.59E+09	-141.96	222.14	0	3060	00:00:00:27
3.59E+09	129.39	116.74	3.59E+09	-142.95	10.54	0	3142	00:00:00:27
3.59E+09	129.5	116.77	3.59E+09	-147.82	16.06	0	3088	00:00:00:28
3.59E+09	129.79	116.68	3.59E+09	-190.8	40.94	0	3092	00:00:00:28
3.59E+09	129.8	116.69	3.59E+09	-179.06	97.12	0	3189	00:00:00:29
3.59E+09	129.86	116.76	3.59E+09	-166.69	-49.43	0	3184	00:00:00:29
3.59E+09	129.98	116.76	3.59E+09	-154.26	22.14	0	3150	00:00:01:00
3.59E+09	129.93	116.97	3.59E+09	-176.4	113.64	0	3064	00:00:01:00
3.59E+09	129.93	116.99	3.59E+09	-171.11	35.13	0	3131	00:00:01:01
3.59E+09	129.94	117	3.59E+09	-184.54	37.79	0	3172	00:00:01:01
3.59E+09	129.93	117.01	3.59E+09	-148.66	192.68	0	3088	00:00:01:02
3.59E+09	129.99	117.04	3.59E+09	-158.98	44.7	0	3162	00:00:01:02
3.59E+09	129.93	117.12	3.59E+09	-169.32	72.77	0	3127	00:00:01:03
3.59E+09	130	117.12	3.59E+09	-166.76	94.69	0	3134	00:00:01:03
3.59E+09	130.06	117.32	3.59E+09	-155.53	72.51	0	3150	00:00:01:04
3.59E+09	130.01	117.32	3.59E+09	-155.85	62.23	0	3122	00:00:01:04
3.59E+09	130.15	117.1	3.59E+09	-116.81	45.12	0	3126	00:00:01:05
3.59E+09	130.32	117.03	3.59E+09	-147.95	-8.28	0	3149	00:00:01:05
3.59E+09	130.21	116.97	3.59E+09	-171.16	7.07	0	3142	00:00:01:06
3.59E+09	130.07	116.85	3.59E+09	-170.89	46.28	0	3144	00:00:01:06

3.59E+09	129.93	116.84	3.59E+09	-165.31	43.84	0	3137	00:00:01:07
3.59E+09	129.87	117.36	3.59E+09	-162.46	119.25	0	3143	00:00:01:07
3.59E+09	129.99	117.7	3.59E+09	-172.38	-22.52	0	3100	00:00:01:08
3.59E+09	130.05	116.08	3.59E+09	-147.95	11.41	0	3146	00:00:01:08
3.59E+09	130.04	117.06	3.59E+09	-157.11	58.08	0	3106	00:00:01:09
3.6E+09	130.51	114.58	3.6E+09	863.26	310.01	0	2527	00:00:18:22
3.6E+09	130.37	114.76	3.6E+09	870.11	297.08	0	2540	00:00:18:22
3.6E+09	130.49	114.82	3.6E+09	859.83	285.53	0	2580	00:00:18:23
3.6E+09	130.37	114.82	3.6E+09	866.97	290.14	0	2523	00:00:18:23
3.6E+09	130.26	114.76	3.6E+09	879.8	302.81	0	2502	00:00:18:24
3.6E+09	130.38	114.76	3.6E+09	860.38	299.98	0	2553	00:00:18:24
3.6E+09	130.2	114.78	3.6E+09	876.03	297.34	0	2517	00:00:18:25
3.6E+09	130.37	114.79	3.6E+09	835.61	296.57	0	2544	00:00:18:25
3.6E+09	130.22	114.79	3.6E+09	878.74	281.86	0	2565	00:00:18:26

APPENDIX F

QUESTIONS FOR SIMULATED CONVERSATION

Questions for Simulated Cellphone Conversation

While driving, you will be asked a series of questions. Answer as best as you can. Please verbalize your answer.

Question Number 1: Patterns and sequence: What is the fourth number in the sequence: 3 – 6 – 9 – (blank)

Question Number 2: Enumerate in correct sequence the colors of the rainbow?

Question Number 3: Math Operation

What is the Square root of 25? *(wait for answer)* How about the Square root of 625?

Question Number 4: What is your college degree major?

Question Number 5: Approximately how many kilometers are there in 1 mile?

Question Number 6: Name three past presidents of the United States?

Question Number 7: What is the initial of your middle name?

Question Number 8: Name three oceans of the world?

Question Number 9: Which is heavier a pound of rock or a pound of cotton?

Question Number 10: Name the four NCAA men's basketball teams who will compete in the final four.

Question Number 11: What are the first four letters of the Greek alphabet?

Question Number 12: Where were the 2006 Olympic Winter Games held?

Question 13: Name four of the six continents.

Question 14: Who invented the internet ?

Question 15: What months of the calendar have more than 30 days?

Question 16: What do the letters DVD stand for?

Question 17: Name the lead actor/actress in the last movie you saw?

Question 18: In algebra, what is the formula for the quadratic equation?

Question 19: Define ergonomics?

Question 20: In computer lingo, what do the letters CPU stand for?

Question 21: What is the most common blood type in humans?

Question 22: What is the largest planet in the solar system?

Question 23: Which is largest: a megabyte, a kilobyte or a giga byte?

Question 24: Who is the current LSU men's Basketball coach?

Question 25: Name the two main ingredients of pasta?

Question 26: Who said the phrase "To err is human, to forgive is divine" ?

Question 27: What is the state capital of Minnesota?

Question 28: What is the capital of your country?

Question 29: Prague is the capital of what country?

Question 30: Which city is nicknamed the "big easy"?

APPENDIX G

NASA WORKLOAD ASSESSMENT FORM (TLX)

NASA RATING SCALES and DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	*Good/Poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

COMBINATION	WORKLOAD FACTORS	
1	Frustration	Performance
2	Mental demand	Performance
3	Frustration	Physical Demand
4	Effort	Frustration
5	Physical Demand	Effort
6	Effort	Temporal Demand
7	Temporal Demand	Frustration
8	Physical Demand	Mental Demand
9	Performance	Temporal demand
10	Frustration	Mental Demand
11	Physical demand	Temporal Demand
12	Performance	Physical Demand
13	Mental Demand	Effort
14	Performance	Effort
15	Mental Demand	Temporal Demand

WORKLOAD FACTORS	RATINGS																		
Mental Demand	Low																		High
	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
Physical Demand	Low																		High
	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
Temporal Demand	Low																		High
	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
Performance	Low																		High
	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
Effort	Low																		High
	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
Frustration	Low																		High
	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10

APPENDIX H

POST EXPERIMENT QUESTIONNAIRE

Post Experiment Questionnaire

Participant's Name:______________________________

Please answer the following questions.

1. How aware of road sign information were you during the drive?

1	2	3	4	5	6	7
Not Aware						Extremely Aware

2. How aware are you of the instructions from the simulator?

1	2	3	4	5	6	7
Not Aware						Extremely Aware

3. Were the instructions from the simulator timely given?

1	2	3	4	5	6	7
Too Late						On Time

4. How safe did you feel during the drive?

1	2	3	4	5	6	7
Extremely Safe						Extremely Unsafe

5. How difficult was it to gather road sign information during the drive?

1	2	3	4	5	6	7
Not Difficult						Extremely Difficult

6. How distracting was the road instruction during the drive?

1	2	3	4	5	6	7
Not Distracting						Extremely Distracting

7. Are you distracted when driving while using your cellular phone? YES NO N/A

8. How confident are you for your safety when using a cellular phone while driving?

1	2	3	4	5	6	7
Feel Very unsafe						Very Confident

9. How did feel about wearing the head mounted eye tracking device?

1	2	3	4	5	6	7
Very Uncomfortable						Feels like not wearing it at all

10. Did the head mounted device distract your driving ability?

1	2	3	4	5	6	7
Not Distracting						Extremely Distracting

VITA

Larry Nabatilan was born in Bay, Laguna, Philippines, on January 22, 1969. He received a bachelor's degree in chemical engineering from the University of the Philippines, Los Baños in April, 1991. He worked for Caltex (Philippines), Incorporated, from 1992 to 1999. While working for Caltex, he enrolled in the Master of Management of Technology program in De La Salle College Lipa. He received the master's degree in May, 1999. He worked as an assistant professor at the University of the Philippines, Los Baños from 1999 to 2002. In August 2002, he enrolled at the Louisiana State University and pursued two degree programs, the master of science in industrial engineering and the doctor of philosophy in engineering science. He received the master's degree in May, 2006. While pursuing the doctoral degree, he was employed as an intern with BASF Corporation under contract with ENGlobal Engineering Incorporated as a Safety and Health Engineer from August 2006 to January 2007. He is a member of the Alpha Pi Mu Industrial Engineering Honor Society and a student member of the Institute of Industrial Engineers.